Solar PV Technology Assessment
Battery for PV Application
Report No. 9

Submitted to

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SUBMITTED BY : TATA ENERGY RESEARCH INSTITUTE

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0.0 The Study

Batteries used in photovoltaic applications are required to have particular properties in order to minimize the system cost, in addition to meeting stringent reliability requirements associated with PV system installations. The battery sizing, installation, operation and maintenance, thus, are fundamentally different from those used in several other energy storage applications. The specific requirements associated with PV battery storage are documented in the current report which is ninth in the series of state-of-art studies on Solar PV Technology Assessment. These studies are undertaken by TERI as part of the sponsored project by the Department of Non-Conventional Energy Sources (DNES) on the assessment of various aspects of PV technology covering both international as well as national status.

The document discusses battery systems commonly used in PV installation, as well as several new options which are found suitable or have been modified suitably to meet PV energy storage requirements. The systems are discussed with respect to their construction, performance characteristics and compatibility with PV systems. Battery testing procedures and sizing, which are relevant for PV applications, a brief discussion on current manufacturing trends in automotive battery industry and lastly, battery terminology are also included.

1.0 Batteries Suitable for PV Power Systems

1.1 Need for energy storage in PV

The amount of photovoltaic electricity produced throughout the day varies from a maximum during peak sunshine hours to zero during the night. Some energy applications function satisfactorily during sunshine hours and therefore get power directly from the PV array. Other applications require a continuous supply of energy irrespective of the time of the day, and hence need a reliable energy storage bank. Energy demand for applications e.g. powering a fan to evacuate hot-air from a room, follows the PV output throughout the day. Energy storage is thus, not needed for such an application. Similarly, pumping and desalinating salt water, generating Hydrogen gas etc. can be done any time of the day directly from the PV array.

On the other hand, energy needs to be constantly available for refrigeration, telecommunication, lighting and for other continuous jobs being performed by electric machines. Such systems can not perform afforesaid functions reliably using PV electricity, unless energy storage is incorporated.

Storage can be achieved in various ways such as mechanical, chemical, magnetic, thermal and in combinations thereof. Several of these energy carriers can fulfill the storage demand but the technological aspects related to viable matching of the sub-systems often restrict the choice

to a few selected ones. Theoretically, all energy carriers can be regenerated and hence can be used in storage systems; the complexities, efficiency and energy densities associated with various regeneration processes may not be very attractive for their utilization. For instance, energy densities obtained from methods based on physical effects are in the range of Wh/kg, while chemicals offer an energy density in the range of 500-1500 Wh/kg due to high reaction energies involved (1). Nuclear material exceed all others in this regard. Energy densities of various energy carriers are presented in exhibit 1.1.

1.2 Battery storage

Among various options suitable for PV energy storage, electrochemical storage in the form of battery is the most commonly used one. Compressed air, flywheel, super-capacitors, super-conducting magnets and Hydrogen are a few other storage technologies (2,3). As per the exhibit 1.2, batteries occupy a good position among various storage technologies and are prone to be cycled in the range of hours. One of the reasons for using battery so commonly for PV electricity storage is that they need direct current for charging. Since PV array generates DC which can directly charge a battery without involving any intermediate sub-system, the battery storage appears tailor-made for PV energy systems. In addition, the battery is also well adapted for operating characteristics of a PV generator, when it is designed to have its terminal voltage floating around the range of voltages associated with the maximum power point

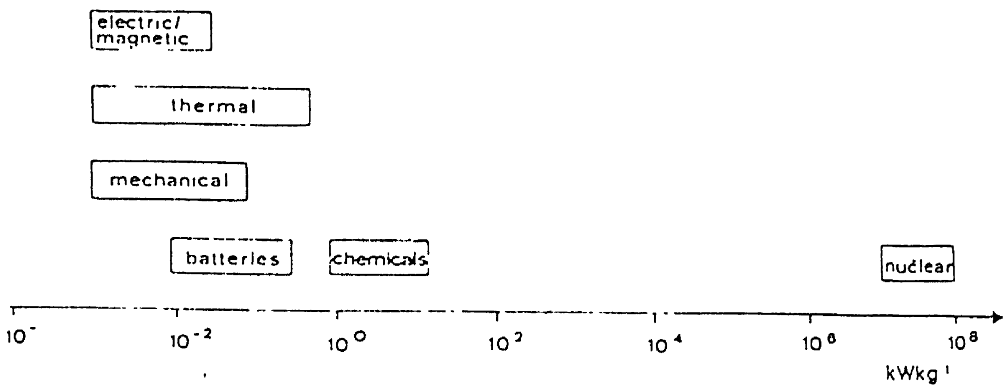


Exhibit 1.1: Energy densities of various energy carriers (Ref. 2)

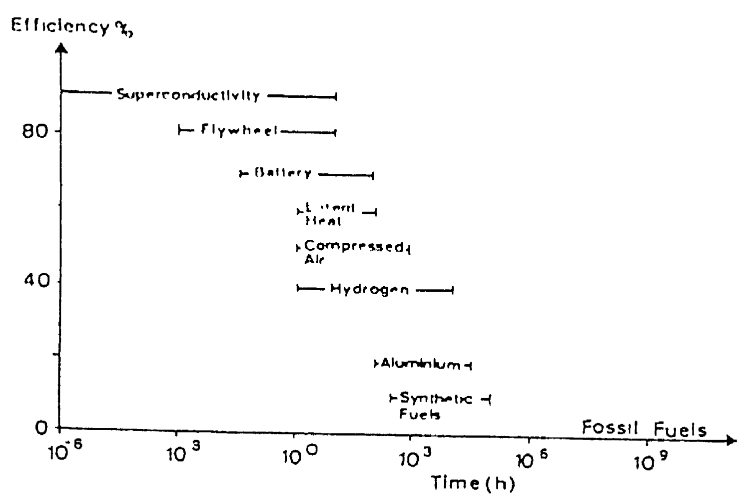


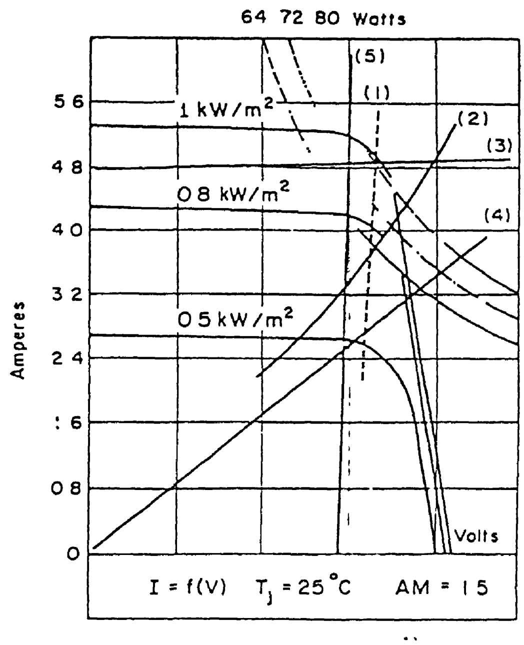
Exhibit 1.2 : Efficiency vs cycle time of various energy carriers (Ref. 2)

of the generator (Exhibit 1.3). It can however, be used for short-term storage only. The high capital cost, low energy capacity and maintenance requirements make it unsuitable for long-term or seasonal storage except in some restricted applications e.g. navigational operations.

The battery charging using PV involves a simple operational principle. In a common PV system e.g. street lighting, the PV array, battery and load are all connected in parallel, having a common voltage V_s. The PV generator current (I_p) is the sum of battery current (I_b) and load current (I_c). The sign of (I_p - I_c) determined by the relative position of the PV array I-V characteristic curve with respect to I_L and dependent on the solar irradiance available, decides the charging (positive sign) or discharging (negative sign) condition. Exhibit 1.4 presents the principle (4).

1.3 Specific requirements of PV battery

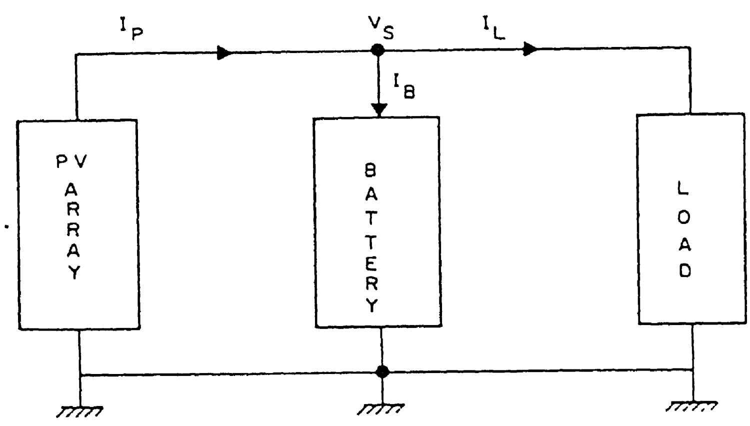
Batteries which are used in PV applications are required to operate fundamentally differently from those used in normal stationary or motive power applications, thus requiring a unique combination of battery properties. Typical stand-alone and remote PV installations require ruggedness, environmental flexibility, capable of unattended operation, easy installation and reliability. These conditions require that the sub-system including the battery should also meet the same criteria set for the PV module. PV modules based on modern technology meet these requirements,



Curves:

(1) maximum power line
(2) centrifugal pump at constant head
(3) positive displacement curve at constant head
(4) resistor
(5) battery

Exhibit 1.3 Typical load characteristics (Ref. 4)



$I_P + I_B + I_L = 0$

$I_B > 0$ Battery Charging

$I_B < 0$ Battery Discharging

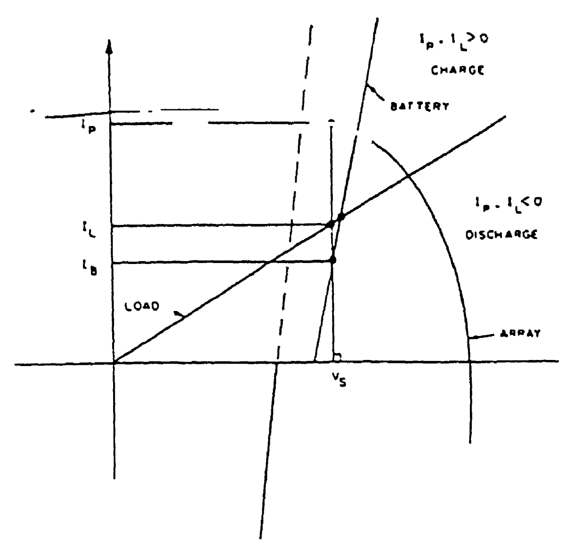


Exhibit 1.4 : Schematic diagram and I-V curves of a PV module and load during battery charging (Ref. 4)

and also provide a routine 20 years of service. For the reliability and availability of the system, the demands made on batteries lie in their:

* ability to withstand cycling both daily and seasonal
* ability to withstand ambient temperature extremes
* ability to operate reliably unattended and with minimal maintenance for a long time period
* ruggedness for transportation to remote sites.

The battery performance parameters critical for PV application are storage capacity, storage and charging efficiency, self discharge, cycle life, capability to operate in various state-of-charge (SOC) modes and operation and maintenance procedure. Unlike other conventional uses of storage battery, those meant for PV applications are characterized by a small or fractional change in state-of-charge (SOC) level on daily charge/discharge cycles, while exhibiting sharp decline in SOC during certain periods in a year depending on the weather and season. They are optimized for a typical low rate operation of a PV system (4).

The batteries specially developed for such applications, usually called solar or photovoltaic batteries are therefore designed to have the following characteristics (5):

* high cycle life
* high capacity appreciation at slow rate of discharge
* good reliability under cyclic discharge conditions
* low equalizing and boost charging requirement

* high watt-hour efficiency and ampere-hour efficiency at different SOC levels
* low self discharge
* wide operating temperature range
* long life, robust design and low maintenance requirement
* highly cost effective
* manufacturing under stringent quality controls.

Desirable battery design features to incorporate above mentioned specific requirements are presented in exhibit 1.5 (6).

1.4 Classification of batteries

The most commonly used storage battery for PV applications is Lead-acid type. Alkaline batteries are also suitable for PV applications, however, at present only Nickel-cadmium has acceptable performance characteristics and life-cycle costs for these applications (4).

Automotive, traction, stationary and maintenance free gelled electrolyte batteries have found their use in different PV applications. Automotive battery (also known as SLI; Starting, Lighting and Ignition battery) has traditionally been used for daily shallow depth-of-discharge (DOD) PV applications e.g. street lighting, although it has only a two to four year life span and a poor cycling ability. Stationary battery is frequently used for applications involving telecommunications, navigational aids, emergency lights, uninterrupted power supply systems etc. These are prone to occasional deep discharge.

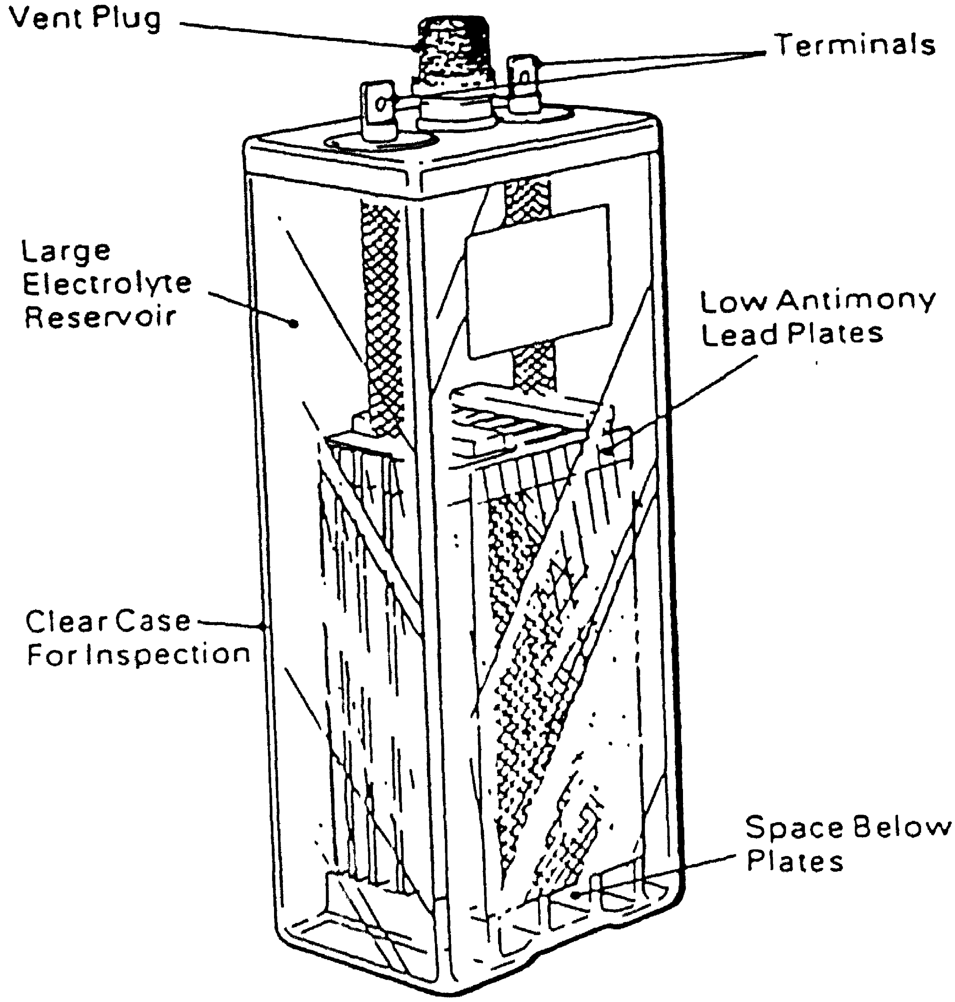


Exhibit 1.5 : Desirable features of a battery for PV
(Ref. 6)

Rechargeable traction or motive power battery is used in electric vehicles, which can also be powered by photovoltaic array. Maintenance free battery is increasingly being required in automotive, traction or stationary applications. Gelled electrolyte or sealed maintenance-free battery is suitable for PV applications, which require completely unattended operations. Research and development on sealed lead-acid battery for PV power application has recently led to the development of a tubular-type battery featuring acid immobilization using silica gel, antimony free Pb grids and thicker plates compared to conventional ones (7). Exhibit 1.6 compares the battery types (4,8).

1.5 Selection of PV battery

Battery, being the state-of-art storage technology for PV applications, is governed by a variety of parameters which can be optimally combined to select the right battery for any particular PV installation.

While selection of a right PV battery requires battery skill, but in most cases the choice is based on lowest price. The system's reliability and durability often suffers due to the inadequate and improper battery selection. Conventionally, the low cost-low maintenance lead-acid automotive battery has been used in most PV installations. Recently, industrial lead-acid battery types with pasted, plante and tubular plates, having grids with low and high antimony content or of pure lead or calcium alloys are being

Exhibit 1.6: Classification and comparison of battery types

Automotive (SLI)	Traction (motive power)
* Designed to deliver large initial current for a short time	* Designed for long life with typical cycle lives of 1000-2000 cycles
* Offer good cycle life at shallow DOD, poor cycle life at deep DOD	* capable of being repeatedly deep discharge to 50-80% of their capacity
* Typical battery is designed to take about 20 deep discharge cycles before its life expires	
* Number of paper-thin plates offer a large surface area which allows currents of 200 A or more to be drawn for a few seconds without damage to the battery.	* Built with thick-grid plates and greater electrolyte capacity for difficult operating conditions.
* Lead-antimony grids are usually used. Grid antimony content is sometimes reduced to minimize self-discharge rate, and small quantities of silver, tin, copper and arsenic are added for grid strength and resistance to anodic corrosion.	* Lead-antimony grids normally used, are expected to provide about 5-15 years of life without deep-cycle operation. Those using lead-calcium grid yield a slightly longer life depending on temperature and other operating conditions.
* Normal battery life is 4-5 years. Sealed automotive battery using lead-calcium grids are also available.	* Suffer from self-discharge problem and may loose up to 30% of rated capacity within several days under no-load conditions.
* A typical 12 V battery has an energy capacity of approximately 0.78 kWh, delivers 300 A for about 20 sec per start corresponding to a DOD of 2.56% of rated capacity.	

Exhibit 1.6 continued

Stationary	Maintenance-free
Poor cycling performance but capable of occasional deep discharge	Manufactured in sealed configurations, but have a means for venting in an event of over pressure
Designed for float-service, capable of being modestly overcharged.	
Usually pure lead grids are used with low strength; also available with lead-antimony and lead-calcium plate.	Lead-calcium grids are used. The battery is acid-limited, having a minimum amount of electrolyte which is absorbed in a gel.
Designed with excess electrolyte to minimize maintenance and watering interval	Need for water addition is eliminated.
Optimal-temperature range for use is 20-30°C, although it has a tolerance of -40°C to 50°C.	Fully charged battery can operate over a wide temperature range.
They have a self-discharge rate.	Characterized by low self-discharge rate and reduced gassing.

Ref.: (4,8)

used frequently. Further, vented, gelled and recombination types make the selection even wider.

In addition, the Nickel-cadmium battery promoters believe its superiority over lead-acid battery on account of better performance characteristics offered by the former. Other alkaline battery systems also compete with lead-acid battery for PV applications for their longer service life and completely maintenance free operation.

A questionnaire based study conducted by I.T. Power Ltd. U.K. (9) to assess user requirements for PV system batteries and ability of various types of batteries to meet these requirements concluded that NiCd batteries are the most cost-effective option for most installations. This is due to the longer life of NiCd batteries, especially in hot climates, in addition to the ease with which they can be used with cheaper electronic controllers as they are undamaged by complete discharge and overcharge. The life-cycle costing of these batteries would indicate that they are a better choice than lead-acid (LA) battery for PV systems.

The study revealed that although battery suppliers rank shallow discharge cycle life significantly higher than deep discharge cycle life, but in the actual operating conditions particularly in hot climatic countries, deep discharge is common. The automotive lead-acid battery's life decreases due to high operating temperatures and deeper cycling as the latter reduces battery size.

The lead-acid battery most suited for PV applications is a high quality design based on traction type battery with low antimony lead alloy plates, as per this study. A comparison of NiCd with high-quality lead-acid battery for PV applications with respect to specific characteristics ranks the former as a better choice (Exhibit 1.7).

The experience obtained at Electricity Generating Authority of Thailand (EGAT) with storage battery for PV installations also suggested that if longer than 2 years of service life is to be expected from a battery mounted at a remote site, low antimonial LA battery with extra electrolyte or NiCd battery would be most suited (10).

Many approaches can be followed for the selection of PV battery. Effect of rate of discharge, battery voltage, and maximum current drain capacity in ampere-hours, watt-hours per weight, watt-hours per unit volume, cost per watt-hour etc. are a few critical parameters for battery selection.

For achieving optimum battery performance in PV applications, the following parameters need to be considered (6):

* cycle life
* rated storage capacity
* depth of discharge
* self discharge rate
* charge and discharge rate
* service at expected temperature extremes
* size and weight
* maintenance requirements
* cost implications

Exhibit 1.7

Importance of battery characteristics (The more stars the better)

	NiCd	High quality LA
in hot climates		
High temperature capacity	***	***
High temperature cycle life	**	*
No damage by full discharge	***	*
Ease of procurement	*	*
Price (capital)	*	**
Maintenance	***	***

Ref.: (9)

2.0 Lead-acid Battery

Majority of photovoltaic systems installed to date uses Lead-acid batteries. Among these, the conventional automotive type has been the most commonly used storage system, particularly in India (11). Owing to a small life-span, typically 2-4 years and poor cycling ability of automotive lead-acid battery, it was not found very suitable for PV applications. Research towards developing lead-acid battery specifically for PV applications lead to several preferred options, viz; tubular stationary battery and maintenance free sealed configurations.

Lead-acid batteries are manufactured in three basic types that differ essentially only in their positive plate construction. The negative plate is made from a pasted grid construction universally. The lead pasted (flat) plate cell has a good voltage regulation characteristics and good power- and weight-to-volume ratios. Easy production method, cheap cost and life time of a decade are its distinctive features (12). Sealed lead-acid recombination cells have pasted plates for both the grids.

Lead-acid configurations using pure lead Plante positive plate having a long life on float charge, although Plante is an expensive lead design. Tubular positive plate type is good for deep cycling applications.

The construction, chemistry and performance characteristics of lead-acid battery conventionally used as a storage

device in PV applications, are briefly discussed in current section.

2.1 Lead-acid battery systems

Batteries of various grid-alloy specifications are available. These are based on:

(i) Pure lead

(ii) Lead-calcium

(iii) Lead/low antimony

(iv) Lead/high antimony

Batteries with lead plates strengthened by calcium or small amounts of antimony are relatively cheap and exhibit good properties for remote applications. Self discharge accelerated by antimony is reduced by using pure lead grids. As per the experience of Electricity Generating Authority of Thailand (EGAT) and BP Solar, Australia, battery with a low antimony content is the best choice for PV applications (10, 13). Exhibit 2.1 presents main features of these four battery types.

2.2 Construction and chemistry

2.2.1 Battery components

Plate grids (positive and negative plates), separators, elements, container, vent plugs and cell connectors are the main components of a battery.

2.2.1.1 The plates

Depending upon the application of the lead-acid battery, grid plates in various sizes and configuration are

Exhibit 2.1: Main features of various lead-acid battery types

Pure Lead	Lead/ calcium	Lead/ low Antimony	Lead/ high Antimony
Monthly self discharge %			
1-3	1-3	2-3	3-10
Cycle life			
Poor	Fair	Good	Good
Robustness			
Weak	Strong	Strong	Strong
Water loss and gassing			
Low	Low	Low	High
Cannot be discharged deeply or recharged too fast.	Battery life is shortened if deep discharged occurs repeatedly. 15-20% of DOD recommended. Poor charge acceptance after deep DOD	Can be repeatedly deep discharged to 50-80% of their capacity. Capable of accepting fast charging rates and delivering fast discharge rates.	
Maintenance			
	Low maintenance required. Offer maintenance-free operation, if enough extra electrolyte is added	Required high maintenance, water level must be restored periodically.	
Miscellaneous			
High initial cost. Offers long life in float applications.	Active material adhesion to the positive plate grid is poor	Plating and slumping of positive plate occur	

Source: Ref. (10) and (13)

used. Faure or flat-plate, Plante plate and Tubular plates are the state-of-art configurations used in PV batteries.

Faure or pasted (flat-plate) type

The active material, which has no rigid form or strength is cured and mounted on a Lead-alloy grid to retain shape and to conduct current to bulk material. The lead-grid is usually a lattice work, onto which the paste is pressed. A variation of the Faure design is the `box´ plate which is used for certain types of stationary battery negative plates.

Plante type plates

Plante plates are characterized by a higher durability In place of pasted active material, the plates consist o lead substrates with electroformed spirals pressed int button-type configurations on the plate. Grooved lea positive plate is another configuration for Plante plates which is normally used in conjunction with pasted negativ plates.

Tubular type

Tubular plates are intended for applications requirii long life and low maintenance. The lead grid in th configuration has a series of spines each surrounded by perforated rubber, plastic or glass-fabric tube with t active material in the annular space. The most econom design in tubular type is considered the one, in which tub are integrated into a one piece Gauntlet made either fr woven or non-woven terylene.

2.2.1.2 Separators

Separators are desirable elements placed between an anode and cathode of a Lead-acid battery to retard the shorting through **treeing, moss** and shedded active material, as also the transfer of undesirable material like Antimony. Suitable separator materials for lead-acid battery are microporous rubber and plastic, resin treated paper base, certain kinds of wool, glass-wool mats, Kieselguhr etc. The desired features of separators are as follows:

* high porosity to allow passage to charged ions of an electrolyte between positive and negative plates
* good insulation to prevent metallic conduction between the two plates
* inertness to oxidation and reaction of electrolyte
* absence of harmful impurities.

Permeability, porosity, pore size distribution, specific surface area, mechanical design and strength, ionic conductivity and chemical compatibility in an electrolytic solution are the critical factors in the selection of separators.

2.2.1.3 Elements

One group comprising each of positive and negative plates along with the separator in between each set of plates forms an element of the battery. An element can have any number of plates of variable size, but the open-circuit voltage of the battery would remain approximately 2.1 V. The increased surface area of the plates either due to the increased number or size will result in a higher voltage

output during discharge at higher rates. The cells are connected together in series by welding post straps of positive group to the post strap of negative group of the next cell, to allow total battery voltage equal the summed individual voltages.

2.2.1.4 Containers

The battery case or container is either a single box to house one element or multicompartment moulded cases for two to six elements with each cell comprising a separate electrical unit insulated from an adjacent cell. Polymers are standard materials used for their construction. The bottom of the container is provided with plate element rests often called `Mud rests´ to provide a dead volume for the accumulation of shedded active material. `Mud rests´ maintain the plates at a certain distance above the bottom of the case.

2.2.1.5 Vent plugs

The covers of the container are moulded in one piece and are provided with vent-filling apertures per cell in addition to a second opening at the end of each cell to fit the tapered terminal posts. Vent plugs or caps fitted in these holes provide access to the battery interior for the purpose of adding water or electrolyte and recording hydrometer readings. Gases are allowed to escape freely from these plugs as they are baffled, while acid is sprayed-back into the cell. In the new-generation vented maintenance-free batteries the cover has only one vent-opening, which is provided at the top or on the side of the case. It also has

a protective hinged coverlet usually combined with flame (explosion) arresting porous components.

2.2.1.6 Cell connectors

Intercell connectors or straps are joined to positive and negative posts of adjoining cells or elements. Their design in multicell battery case is of a considerable importance for exhibiting properties e.g. high-rate capabilities, minimum IR losses and high power delivery at subzero temperatures. The construction material is usually pure lead, lead-antimony alloy or lead-plated copper. They are designed to carry currents equal to about five times the nominal ampere-hour capacity.

2.2.2 Active chemical materials

Lead sponge, lead oxide and electrolyte comprising of sulphuric acid and water form the active chemical materials of a lead-acid battery system.

Pure lead having a density of 11.3 g/cm^3 at 20°C, resistivity of approximately 2.1 x 10^{-5} Ω cm at 18°C and melting point of 327°C is used as an active material for negative plate of the battery. It is present in a highly porous form, called 'sponge' lead in pasted electrochemically formed negative battery plates.

Lead dioxide constitutes an active material of the charged positive plate in a Lead-acid battery. It is never used as a raw material during the manufacturing process, but is prepared in situ during the electrochemical formation process.

An aqueous solution of sulphuric acid is the electrolyte used in lead-acid battery. Based on the overall electrochemical reaction, 3.66 gms of H_2SO_4/cell/Ah are theoretically required (14). The purity of the electrolyte solution is of a critical importance as the sponge lead negative plates get affected by the ionic impurities depositing on them, thereby inducing self-discharge through local galvanic action.

2.2.3 Chemical reactions

(i) at negative plate

$$Pb + SO_4^{-2} \underset{\text{charge}}{\overset{\text{discharge}}{\rightleftharpoons}} PbSO_4 + 2\bar{e}$$

(ii) at positive plate

$$PbO_2 + SO_4^{-2} + 4H^+ + 2\bar{e} \underset{\text{charge}}{\overset{\text{discharge}}{\rightleftharpoons}} PbSO_4 + 2H_2O$$

(iii) Net reaction

$$PbO_2 + Pb + 2H_2SO_4 \underset{\text{charge}}{\overset{\text{discharge}}{\rightleftharpoons}} 2PbSO_4 + 2H_2O$$

A fully charged battery will have all the acid in its electrolyte with the specific gravity at its maximum. The active material at the positive plate will be lead peroxide and on the negative plate will be sponge lead. As the battery discharges, some of the acid from the electrolyte present in the pores of the plates gets separated thus changing the active material to lead sulphate and water. As the discharge process continues, more acid will leave the

electrolyte, making it a weak one thereby resulting in a gradual decrease in specific gravity of the electrolyte.

The reverse of it takes place, when the battery is placed on charge. The acid from the sulphated active material on the plates is driven back to the electrolyte, thus increasing the specific gravity of the electrolyte. The specific gravity of the electrolyte will continue to rise, until all the acid is driven back to the electrolyte and no sulphate ion is left on the plates. No further increase in specific gravity will take place on additional charging.

As the cell approaches the full charged condition, all the charging current cannot be utilized, the excess of it electrolyzes water into Hydrogen and oxygen is gaseous forms. This is the reason for frequent water requirement in the battery.

The decrease in the specific gravity on discharge is proportional to the number of ampere-hours discharged.

2.3 Battery characteristics

2.3.1 Storage capacity

2.3.1.1 Ampere-hour capacity

The magnitude of discharge current available for a specified length of time is valid only at a specific rate and temperature. For example, a 6 V battery rated at 100 Ah at 10 h rate can deliver 10 A continuously for 10 hours equivalent to 0.6 kWh of energy. The same battery at 24 h rate will give a maximum of 120 Ah, equivalent to 0.72 kWh of

energy. Exhibit 2.2 a illustrates the relationship. Factors determining the battery capacity are battery size, construction, temperature, concentration of electrolyte, plate history, temperature and discharge rate.

2.3.1.2 Watt-hour capacity

Energy capacity or watt-hour capacity is the time integral of the product of discharge current and voltage from full charge to cut-off voltage. It can be determined using the following equation:

$$WC = Ah \times V \times BF$$

where WC is the usable watt-hour capacity

Ah is amphere-hour capacity

V is the battery voltage at 60% SOC and room temperature (or 2 V per cell assumed average voltage during discharge.

BF is the fraction of battery available for use.

Watt-hour capacity denotes the amount of energy, which the battery can store. A battery's storage capacity degrades or reduces with age depending on the number of charge/discharge cycles, depth of discharge and operating temperatures.

Based on Ah and Wh capacities, the battery efficiency can be expressed either in terms of Ah efficiency or Wh efficiency. While the Wh efficiency is the ratio of the maximum energy output to maximum energy input, Ah efficiency is the battery's total current output divided by total

current input over a full charge/discharge cycle. Since the charging voltage is appreciably higher than the voltage during discharge, the Ah efficiency figure is misleading and is often higher than the Wh efficiency under the same conditions.

2.3.1.3 Effect of temperature on battery capacity

A decrease in battery's operating temperature below room temperature results in a decreased storage capacity. At lower temperatures, its discharge voltage is decreased, thereby reducing its power output. The lead-acid battery is permanently damaged at extreme temperatures. The lead-acid battery capacity usually decreases at the rate of 1% for every drop of $1^{\circ}C$ in the battery temperature.

2.3.1.4 Effect of discharge rate on battery capacity

A battery has a larger ampere-hour capacity at longer discharge rates, as more time is available for the electrolyte to penetrate deeper into the battery plates. The acid circulation into the pores of the plates and diffusion of water is too slow to sustain the higher discharging rate during short duration, resulting in small utilization of the electrolyte and active plates material.

Exhibit 2.2 a, b present effect of discharge rate and temperature on battery capacity

2.3.2 Cycle life

Cycle life characterizes the number of times a battery can be charged and discharged. It relates the number of

cycles to a specified depth of discharge at a specified temperature and discharge rate until the battery's 'end of life' is reached. The depth of discharge (DOD) is the allowable level, to which a battery can be discharged without causing any damage. The 'end of life' typically is the state, where the battery capacity falls below 20% of its rated capacity.

The life of a battery is enhanced by a shallower DOD, while a deeper DOD does the opposite. Although the longer discharge rates enhance the battery capacity, yet its life owing to the internal stresses resulting from the deeper penetration of acid intc the plates is reduced. Exhibit 2.2 c shows the effect of DOD and temperature on lead-acid battery life.

2.3.3 Specific gravity of electrolyte

The level of energy or state of charge (SOC) at any point of time is the amount of energy available in the battery. Specific gravity of the electrolyte at any instant is indicative of the SOC of the battery. It is a measure to determine the sulphuric acid content of the electrolyte at any given temperature. Exhibit 2.3 (a,b) give the range of specific gravity for different types of lead-acid battery in tropical and temperate zones. It also gives typical specific gravity values and battery open circuit voltages for various SOCs. Specific gravity of 1.265 corrected to 26.7°C (80°F) is assumed for a fully charged battery.

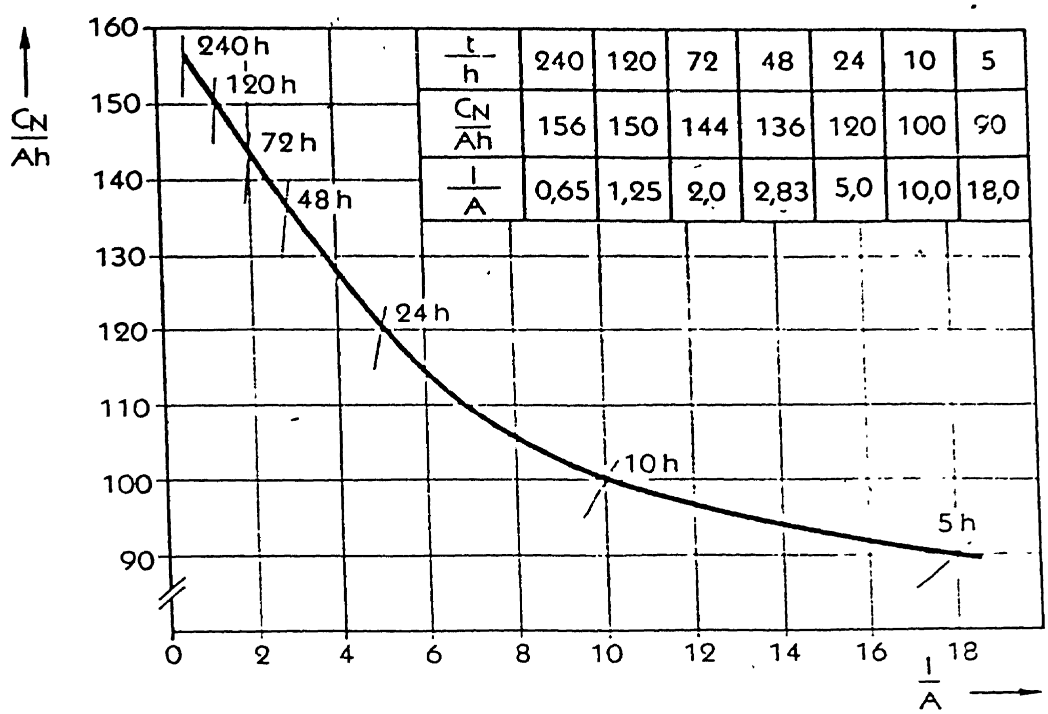


Exhibit 2.2 a: Discharge characteristics at various rates (Ref. 34)

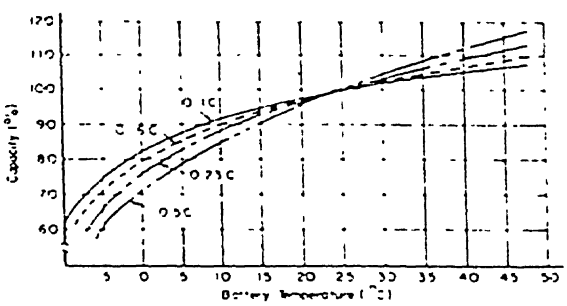


Exhibit 2.2 b: Battery temperature and capacity at various rates (Ref. 4)

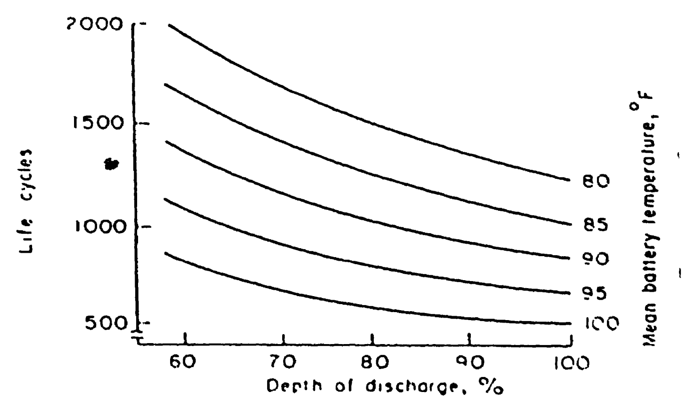


Exhibit 2.2 c: Effect of DOD and temperature on battery life (Ref. 4)

Exhibit 2.3a

Specific gravity range for various types of lead-acid battery

Battery type	Temperate climate fully charged	Temperate climate discharged	Tropical climate fully charged	Tropical climate discharged
Automotive	1.260-1.280	1.120	1.210-1.240	1.080
Traction	1.260-1.280	--	1.210-1.240	--
Stationary	1.200-1.225	--	1.200-1.225	--
Photovoltaic	1.300	1.075-1.130	1.225	1.040

Ref.: (4)

Exhibit 2.3b

Typical open-circuit voltage and specific gravity values different SOCs

SOC (%)	Specific Gravity	Voltage (12 V battery)	Voltage (6 V battery)
100	1.265	12.7	6.3
75	1.225	12.4	6.2
50	1.190	12.2	6.1
25	1.155	12.0	6.0
discharged	1.120	11.9	6.0

Ref. (4)

Specific gravity determination is mostly made by a hydrometer. However, since hydrometer floats are calibrated to give a true reading only at fixed temperature, a temperature correction factor must be applied to any hydrometer reading, if taken at temperatures other than 26.7°C. Generally, a temperature correction factor of 0.004 for specific gravity is used for every 5.5°C (10°F) change in temperature.

Electrolytes with a low specific gravity have a high freezing points, which decreases with an increase in the specific gravity or the battery SOC.

2.3.4 Self discharge

In a standing mode, a small amount of battery capacity will be consumed by local chemical reactions. A battery will therefore slowly self discharge, if left unused. Exhibit 2.4a shows lead-acid battery self-discharge rates. It increases with increasing cell temperatures.

2.3.5 Internal impedance

The high current requirement for certain applications demands that battery should be designed with low internal resistance. Design parameters for the low resistance would be the formation of a conductor with large cross sections and minimal lengths, separators with maximum porosity and minimum backweb thickness and electrolyte having low resistance (8).

The resistance of a lead-acid battery linearly increases during discharge with the decrease of the specific gravity of the electrolyte. The difference in resistance between fully charged and discharged state is approximately 40%.

2.3.6 Charge and discharge voltages

The charging voltage increases with an increase in SOC and increasing charge rate as shown in exhibit 2.4b. Efficient charging takes place in region A of the curve. Electrolysis begins in region B, when the end of charge is being approached. When the terminal voltage approaches near 100% SOC in region C, excessive gassing and loss of electrolyte occurs. Thus overcharging can cause the active material to flake off, thereby reducing the battery capacity and life.

On discharge, there is a decrease in the voltage due to internal resistance. The drop increases with an increase in the discharging current. At a continuous rate of discharge, the voltage decreases as the discharge progresses. For low discharge rates, voltage drops gradually till the knee of the voltage curve is reached. Further discharge results in a rapid fall to and below an effective value of final or cut-off voltage (exhibit 2.4 c). Discharge voltage is also affected by the operating temperature of the cell. As the excessive charging causes the battery voltage to rise prohibitively higher and excessive discharging pulls to too low, the battery is protected using different types of voltage-regulators to maintain the voltage within acceptable

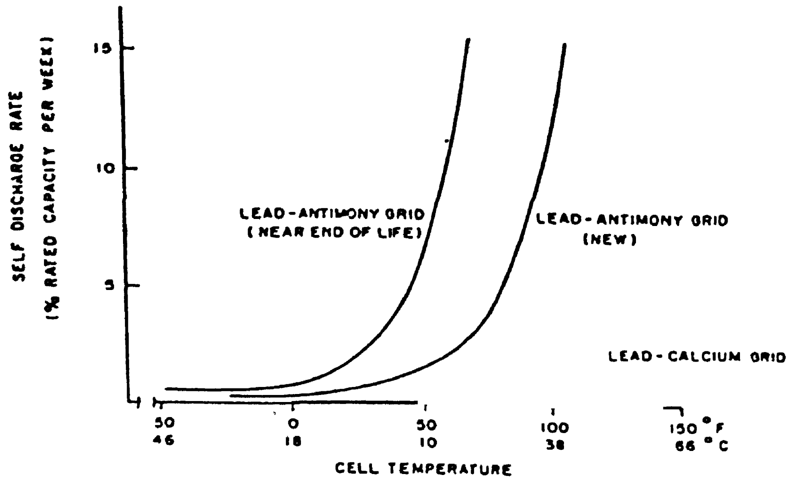


Exhibit 2.4 a: Lead-acid battery self discharge rates
(Ref. 4)

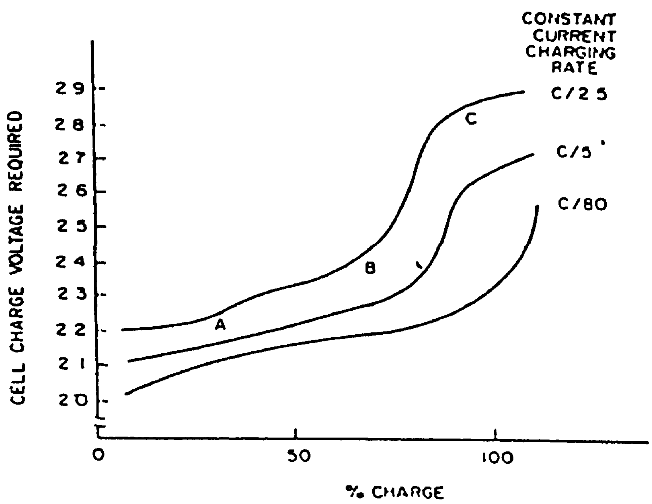


Exhibit 2.4 b: Typical charge voltage characteristics
(Ref. 4)

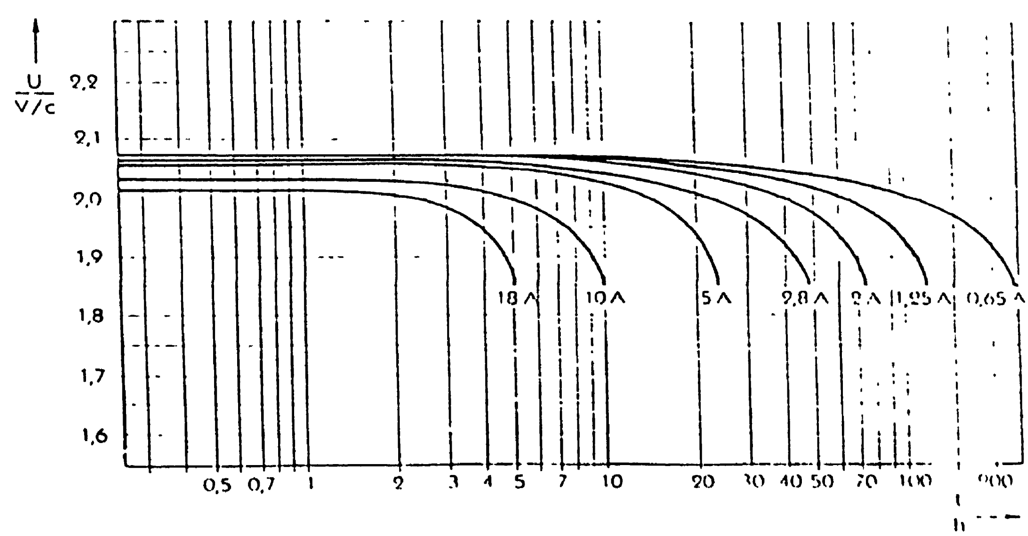


Exhibit 2.4 c: Discharge voltages in dependence upon the discharge current related to 100 Ah capacity
(Ref. 34)

range or `window'. The end-of-discharge voltages are set to maximize capacity, retaining a long battery life. The end-of-charge voltage would produce enough gassing to mix the electrolyte and to reduce stratification which is caused by very low charging rates.

The recommended window for shallow-discharge cell is (2.50-2.54) V to 1.90 V per cell, while for deep-discharge battery, it is (2.60-2.65) V to 1.70 V per cell.

2.3.7 Charging methods

The charging methods used for charging lead-acid battery depend on the charging time required, environmental conditions etc. Charging of a secondary battery is somewhat inefficient as more capacity is required to be put in the battery during charging from the one than was taken out during the previous discharge cycle. The amount necessary for recharge depends on the depth of discharge, the method of recharge and the temperature.

Some of the requirements for proper charging of all types of lead-acid battery are as follows (8):

(i) The charging current at the start of recharge can have any value, which does not produce an average cell voltage in the battery greater than the gassing voltage.

(ii) During the recharge and until 100% of the previous discharge capacity has been returned, the current should be maintained to keep the voltage lower than the gassing voltage.

(iii) When 100% of the charged capacity has been returned the charge rate will have normally decayed to the charge finishing rate. The charge should be finished at a constant current, in no case higher than this rate.

Commonly followed charging methods which satisfy these requirements are (4,8,15).

* constant potential charging
* constant current charging
* taper charging
* pulse charging
* trickle charging
* float charging

2.3.7.1 Constant potential charging

It is the most efficient and fastest way of charging, where the charging circuit is tied to the battery. The modified constant potential charging is accomplished in two ways; one with constant initial current and other with constant start and finish rate. The charging circuit has a current limit and this value is maintained until the predetermined voltage is reached. The voltage is then maintained constant, until battery is called on to discharge. The current limit and the constant voltage values are influenced by the time interval, when the battery is at constant potential and in a 100% state-of-charge. With constant start and finish rate, the charger is normally set at 2.39 V per cell (the gassing voltage) and the starting current limited to 16 to 20 A per 100 Ah of the rated 6 h

ampere-hour capacity by means of series resistor. This initial current is maintained until the average cell voltage in the battery reaches 2.39 V. The current after decaying to a finishing rate of 4.5 to 5 A per Ah is maintained to the end-of-charge.

The modified constant potential charging is preferred for PV battery systems. Achieving a full recharge capacity with a low constant potential requires the proper selection of the starting current based on the manufacturer's specifications.

2.3.7.2 Constant current charging

Constant current charging is accomplished by the application of non-varying current source. This method is effective, when many cells are to be charged in series. It tends to eliminate any charge imbalance in a battery by charging all cells equally due to its non-dependence on charge voltage.

2.3.7.3 Taper charging

Taper charging is similar to the modified constant potential charging. In this case, the initial rate of charging is limited but the taper of voltage and current is such that the 2.39 V per cell at 25°C is exceeded prior to the 100% return of the discharge Ah. The method results in gassing and an increase in cell temperature, the degree of which depends on charger design. The end-of-charge is often controlled by a fixed voltage rather than fixed current.

In this case, the charger is periodically isolated from the battery terminals and the open-circuit voltage is measured. If the V_{OC} is above a preset value, depending on the reference temperature, the charger does not deliver energy. When the V_{OC} is below that limit, the charger delivers direct current pulses for a fixed duration, extending up to 100% duration if battery charge level is too low.

2.3.7.5 Trickle charging

A trickle charge is a continuous constant current charge at a low (about C/100) rate, which is used to maintain battery in its fully charged condition, recharging it for losses due to self-discharge as well on to restore the energy consumed during intermittent use of the battery. This method is typically used for an automotive battery, which is removed from its source of charging.

2.3.7.6 Float charging

It is a low rate constant-potential charging used to maintain the battery in a fully charged state This method is usually used for stationary battery, which is charged from a DC bus. The float voltage for non-antimonial grid battery containing electrolyte of 1.210 specific gravity having an V_{OC} of 2.059 V per cell at 25°C is 2.17 to 2.25 V per cell (8).

Exhibit 2.5 (a-d) present charger and battery characteristics for various charging methods.

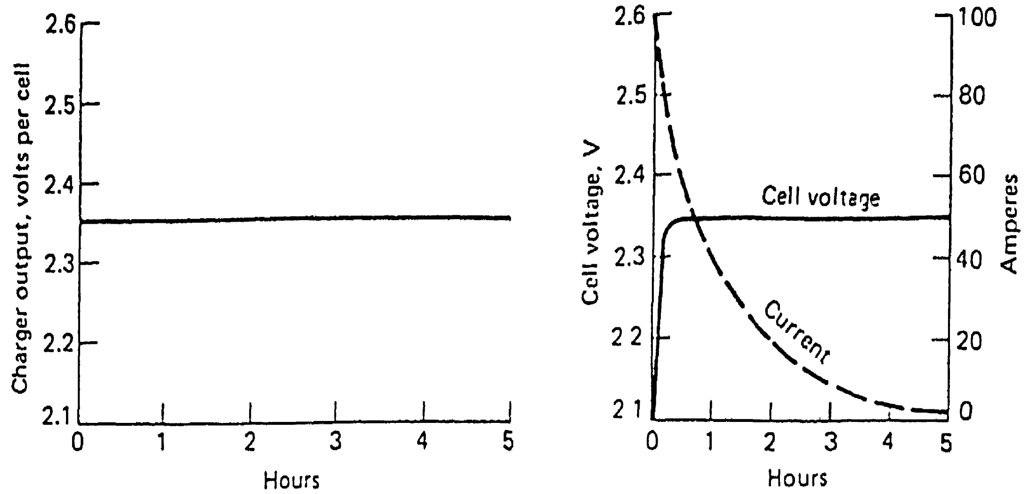


Exhibit 2.5 a: Constant potential charging of LA batteries (Ref. 8)

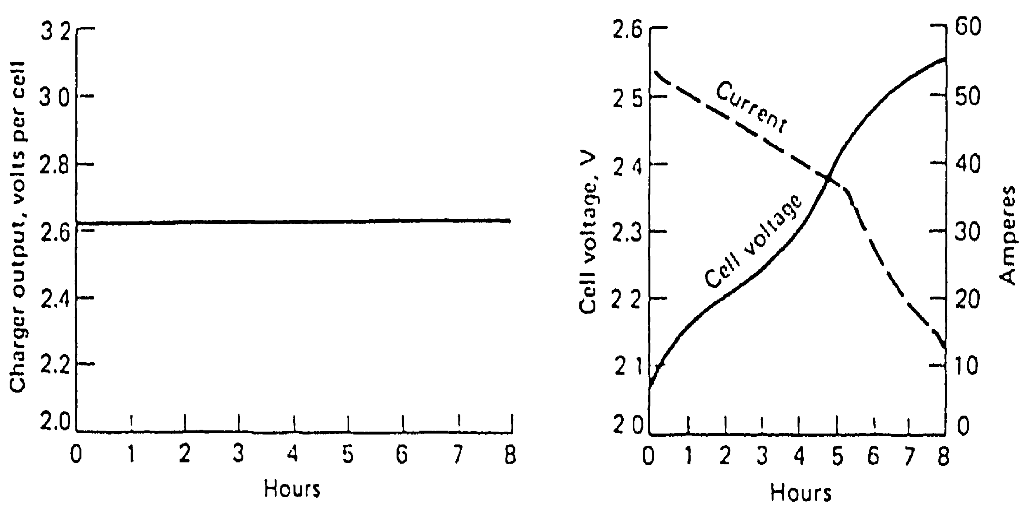


Exhibit 2.5 b: Modified-constant-potential charging of LA batteries (Ref. 8)

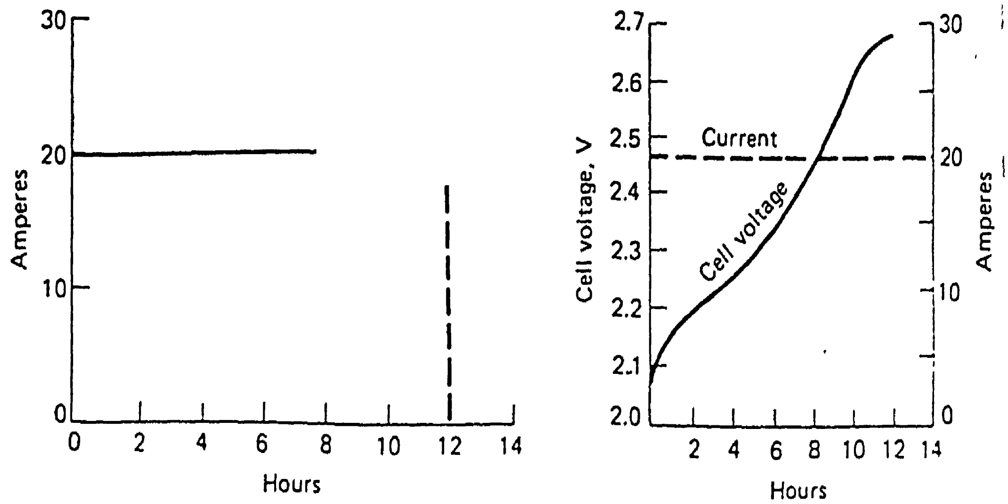


Exhibit 2.5 c: Single-step constant-current charging of LA batteries (Ref. 8)

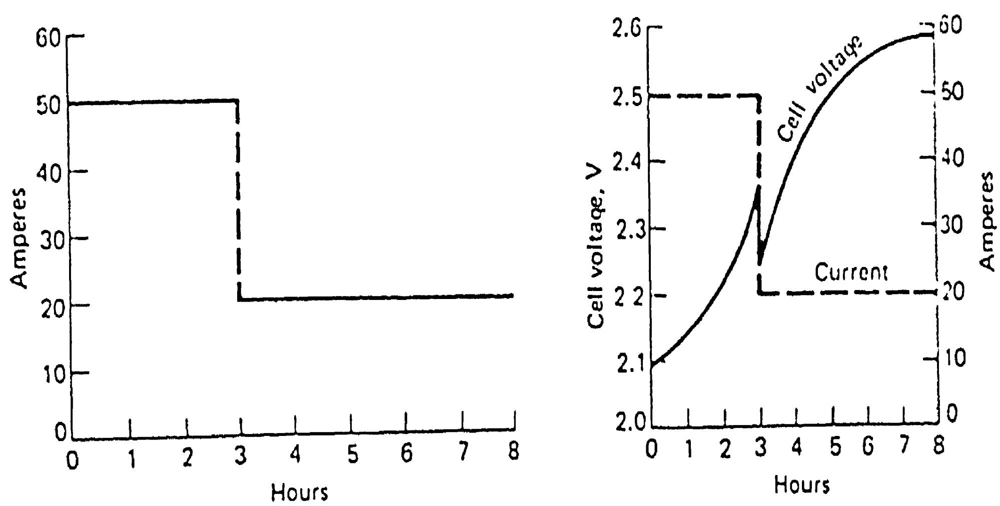


Exhibit 2.5 d: Two-step constant-current charging at LA batteries (Ref. 8)

2.3.8 Failure modes

Failure modes of automotive lead-acid battery are described in exhibit 2.6

2.4 Maintenance-free battery

Maintenance-free lead-acid battery used in PV systems has been developed to eliminate the need of adding water for maintaining cell capacity. The general approach is to replace conventional lead-antimony grid with the one which is less prone to self-discharge and gassing.

The most commonly used maintenance-free lead-acid battery is the small sized one used for standby applications and portable appliances. The electrolyte is in the immobilized state, which is achieved by any of the following means (14).

* Conversion to a thixotropic gel with additions of upto 5 Wt% silica having submicrometer particles with or without additional support provided by a glass fibre mat.
* Use of sodium silicate.
* With absorbent separator-matrix components usually made of cellulose or glass fibres.

In order to increase hydrogen overvoltage and decrease self-discharge, lead calcium grid alloys are usually used in addition to using phosphoric acid to minimize positive active material shedding. The vents of these batteries are designed as check-valves allowing excess pressure to escape. Some designs have achieved a high degree of reliability in terms of possible discharge cycles.

Exhibit 2.6 : Failure modes of automotive lead-acid battery

Open circuits	Terminals Cell to terminal Cell to cell Broken straps Plate off
Short circuits	Plate to strap Plate to plate (plate fault) Plate to plate (separator fault) Plate to plate (sediment/moss) Vibration short
Poor plates	Overcharge/overhead Grid corrosion Paste adhesion Paste sulphation Paste underformed
Worn out	Worn out undercharge Low level (electrolyte) Terminal corrosion Underformed
Serviceable	Serviceable Discharged
Broken	Broken contained Broken cover Damaged terminal Internal damage Other

Ref.: (3)

2.4.1 Hermetically sealed configuration

The most significant designs amongst maintenance-free batteries is the hermetically sealed configuration. Two approaches are generally followed for lead-acid sealed battery configurations:

(i) Operation based on oxygen cycle, where hydrogen evolution is suppressed and the evolved oxygen is recombined at the partially discharged negative electrodes.

(ii) Catalytic recombination of Hydrogen and oxygen inside or outside the battery.

The second approach viz.: use of a recombinator poses practical problems viz. selection of the right kind of catalyst, its placements inside or outside the battery etc.

The approach based on oxygen cycle has been found more attractive for the sealed designs. The essential design requirements are (16):

* Highly absorbent separator, having high pore volume and should be sufficiently resilient to diffusion to the contours of the plate surface under compression.
* Volume of electrolyte must be accurately controlled.
* Plate and separators must be maintained under a uniform pressure.
* Battery must be sealed and leak proof.

Battery incorporating above designs have high gas recombination efficiencies, very low water loss, high energy

density per unit volume and weight, better charge acceptance and improved vibration and shock resistance. The compact design also results in a low internal resistance as compared to both plate and flat-plate configurations.

The success of this technology is evident from the fact, that at present there are at least 12 manufacturers producing a wide range of sealed lead-acid battery for variety of applications, as compared to very few engaged in the year 1973 (16). Such batteries used in PV installations promise to improve the system reliability and overall life.

2.4.2 Comparison with conventional flooded type design

Exhibit 2.7 compares the conventional flooded type lead-acid battery design with a sealed maintenance free design.

2.5 Advanced tubular plate lead-acid battery for PV systems

Conventional flat plate, plante and/or tubular type stationary and traction cell designs have all been used in remote area PV power supply applications. However, none of the designs has ideally met the performance and O&M criteria as expected of a PV battery. Lead-acid battery specifically developed for PV systems, fulfilling all the requirements, incorporates advanced tubular plate design (17).

The continuous anodic polarization of tubular-plate electrodes under stationary mode of operation indicates the preference of pure lead or low antimony alloy, while the cyclic anode/cathodic polarization of motive power or traction conditions requires high antimony lead alloy grids.

For PV applications, the antimony content of [illegible] grid alloy should be low to minimize self-discharge and water-loss effects, yet sufficiently high to ensure adequate service life.

The tubular-plate design is preferred over flat-plate design on account of the improved active material utilization of the positive plate in the former design. The inferior performance of the flat-plate design is a result of the resistance polarization and diffusion polarization during discharge. The tubular-plate design out-performs their flat-plate counterpart at higher discharge rates (c/10 and c/5).

To achieve greater mechanical stability, improved active mass utilization, reduced grid corrosion and superior active material/grid weight ratio, the positive grid design developed by CBS Batteries, U.K. utilizes granular form of blended battery oxide. It is composed of spherical particles with more than ~80 wt.% falling within the size range (125 150) μm (17).

These design features incorporated by CBS Batteries in an advanced tubular-plate battery, maintained the PV energy-storage system at a price of 0.10 $/Wh in 1989 (17)

Exhibit 2.7

Conventional flooded type design vs. sealed maintenance free design

Conventional flooded type	Sealed maintenance free design
Technology	
Conventional lead antimony alloy, newer low antimony alloys are also used. Higher corrosion. Less life.	Patented hybrid "MFX" alloy. Capable of deep discharge and Maintenance free operation. Low corrosion - Long life.
Tubular positives, pasted negatives with rubber or synthetic separators and hard rubber containers with flooded acid. Heavy and bulky.	Pasted positive and negative plate with highly absorbant synthetic separators and plastic containers. Compact and up to 30% lighter.
Normal vent plugs.	Oxygen recombination system, with no external gassing. Fully explosion resistant. Self resealing safety plugs provided.
House Keeping	
Separate room required to avoid accidents due to hazardous gases.	Batteries can be housed in the usual working area as there is no emmission of gases/fumes.
Special ventilation required	Normal ventilation adequate.
Special wooden insulated racks required to withstand acid spills.	Inexpensive, easy to handle, slotted angle racks can be used.
Acid fumes corrode the battery terminals, require frequent washing with water and Sodium Carbonate.	No corrosion or deposits; battery comes with a false cover; can be cleaned or dusted easily.
Maintenance	
Water level depletes, needs regular topping up with distilled water and occasionally with electrolyte to make up for spillages. 10% decrease in	It is based on recombination technology and is totally sealed. Needs no topping up. Only 3% decrease in electrolyte after 1500 cycles of 80% DOD (negligible).

electrolyte leads to 20% drop in efficiency.	
Skilled manpower required for periodic/routine maintenance.	No extra manpower required for maintenance. Fit and forget concept.
<u>Operation under Freezing Conditions</u>	
Failure due to freezing of electrolyte is possible, especially in discharged cells.	Low Temperature and state of discharge do not cause battery failure.
<u>Stratification/Equalising</u>	
Operation in partially discharged condition for a long period leads to stratification. Cell capacity is consequently reduced. Needs equalising charge regularly.	Acid is completely absorbed in the separator. Hence no startification. Capacity of battery is unaffected. Needs no equalization charge under normal operating conditions
<u>Initial Charging</u>	
Electrolyte filling and charging required at site. Takes up to 100 hours.	Easy installation, as available in factory charged condition.
<u>Charge Acceptance</u>	
Low charge acceptance. Takes more than 16 hours for normal charge.	Higher charge acceptance. Can be fully charged in 8-10 hours.
<u>Average Discharge Voltage</u>	
Lower discharge voltage. Hence at constant power discharge, shorter discharge durations.	Higher discharge voltage. Therefore, longer discharging periods at constant power.
<u>Self Discharge</u>	
Self discharge up to 3-4% per week.	Very low self discharge rate of 0.5 to 1% capacity per week.
<u>Handling</u>	
Battery cannot be transported in charged condition.	Charged battery can be transported.

Battery has to be installed in an upright position.	Battery can be installed either in a vertical or horizontal position can be stacked in horizontal tiers resulting in space savings.
Explosion	
Prone to explosions in the presence of sparks.	Battery explosion proof because of specially designed safety vent plug.

Source: Ref. (18)

3.0 Alkaline Battery

Although lead-acid battery is the most widely used storage system in PV applications, its capacity utilization is severely restricted due to its life dependence on depth of discharge. In addition, the unique charge/discharge characteristics of PV system further reduce the battery life as its complete recharging and cell equalization can not be achieved on a routine basis (19). A few typical problems associated with the use of Lead-acid battery in PV installations are as follows:

(i) In certain cases, the differential between the charge and discharge battery voltage is quite high, approximately 18 V for a 48 V battery system. This may effect the inverter operation.

(ii) Electrolyte stratification is another problem in large systems.

(iii) Quality and availability of water particularly at remote installations pose electrolyte maintenance problems.

(iv) Extreme temperature variations may affect the battery operation significantly.

Constraints such as these lead to the application of alkaline batteries in PV installations, the most commonly used one is the Nickel-cadmium battery system. Nickel-iron, Sodium-sulphur, Zinc-bromine etc. are a few other options considered.

3.1 Nickel-cadmium system

3.1.1 Design and performance parameters critical for PV applications

There are several NiCd battery systems commercially available for use in PV applications. Its manufacturers claim the superiority over lead-acid battery inspite of the former's high capital cost (12,20,21). One major reason for the promotion of NiCd battery in PV applications is its longer life and operational reliability, particularly where the battery is exposed to daily and seasonal cycling at various depths of discharge.

These performance features are obtained in NiCd battery on account of its physical parameters. Some of these are:

* Absence of grids to support active materials which are contained in pockets of perforated nickel plated steel strips joined to the steel plate material. The current collectors and mechanical connectors are also made of steel, hence there are no mechanical parts which corrode in the internal cell environment.
* The perforated steel enclosures apply physical pressure to the active materials, which promotes conductivity and minimizes electrode swelling. There is no shedding of active materials.
* The alkaline electrolyte does not react with the steel, as a result of which, the supporting structure for the battery remains intact for the lifetime of the battery.
* The electrolyte does not change during charge and discharge. It retains its ability to transfer ions

between the cell plates irrespective of its charge level. The NiCd battery can operate at any SOC. There is no stratification in NiCd battery.

* It can be shorted and stored discharged without any permanent degradation. In addition, it has a high tolerance to being overcharged.
* NiCd battery contains appreciable volume of the electrolyte. The separator rods which are used solely to keep positive and negative plates electrically separated from each other, have no impact on the internal battery parameters.
* No mossing (sedimentation) or treeing takes place in NiCd battery.
* There is no sulphating process in NiCd battery.

3.1.1.1 Construction and chemistry

The NiCd battery has Nickel hydroxide and a mixture of cadmium and iron as the active material for positive and negative plates respectively. The electrolyte is a solution of potassium hydroxide. They are manufactured in two basic types:

(i) **Sealed Type**: It has a pressure relief valve built into the cell which prevents explosion, if the cell becomes heated or overcharged by releasing the gas into the atmosphere. These can be recharged many times and are not adversely affected by long standing either in charge or discharge mode.

(ii) **Vented type**: These have resealable vents that can open and close under small pressure changes. Pocket-plate and sintered-plate types are the two configurations available. The sintered-plate offers about 50% higher energy density than what is offered by pocket-plate.

NiCd cells are available in button, cylindrical and rectangular configurations and capacities.

The electrolyte is used solely to conduct current between the plate, it is not utilized chemically in the charge-discharge reactions. The specific gravity is normally 1.16 to 1.19 at 77°F. The charge-discharge reaction is:

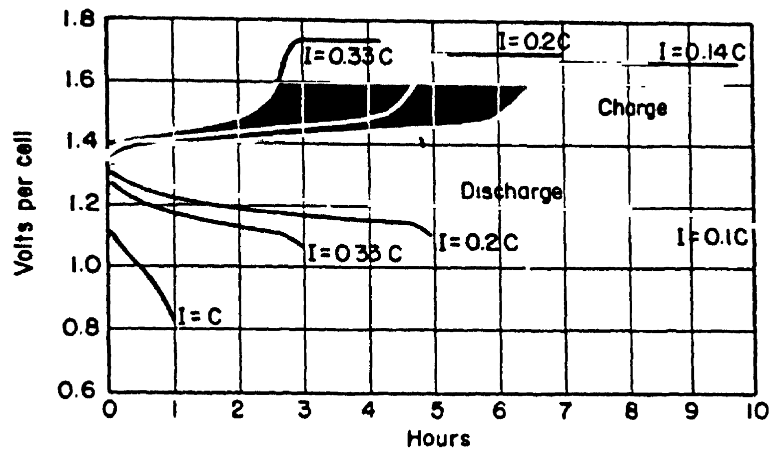
$$2Ni(OH)_3 + Cd \rightleftharpoons 2Ni(OH)_2 + Cd(OH)_2$$

The output voltage (1.2 V) per cell of the battery staying stable to the stage of complete discharge resisters a sharp fall thereafter. The complete discharge state is usually indicated by a cut-off voltage of 1 V.

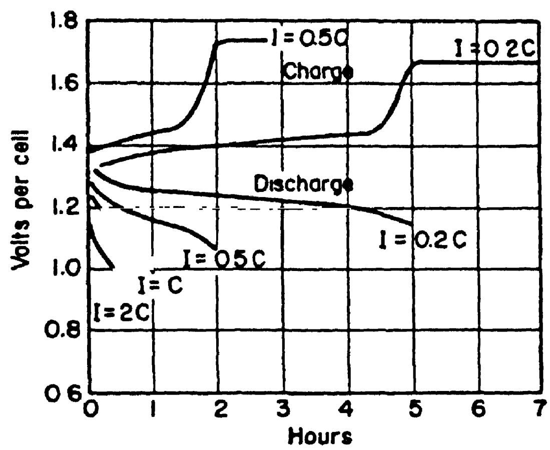
Exhibit 3.1 represents charge and discharge characteristics of NiCd battery. It can accept a high charge rate (C/1) and is capable of operating under continuous overcharge condition.

3.1.1.2 Charging efficiency

Under the charging conditions expected in PV installations, the NiCd battery offers more than 80% charging efficiency, almost similar to the value offered by a Lead-acid battery (12). It however, falls with time in lead-acid system which is not the case with NiCd battery system.



a)



b)

Exhibit 3.1: Charge and discharge characteristics of NiCd cells at various constant rates of 20°C

(a) Normal resistance battery

(b) Extra low-resistance battery

(I is the current, C is the capacity of 10 h rate)

(Ref. 4)

3.1.1.3 Self discharge rates

Battery with a low discharge rate is desirable for use in PV systems, as the one with a high discharge rate requires comparatively larger PV array. NiCd battery is characterized by low self-discharge rates; its capacity drops to about 80% in a year under open circuit voltage conditions. Thereafter, this rate remains within 5% loss per annum. This property of NiCd battery eliminates any compensatory need for self-discharge when used in PV systems.

3.1.1.4 Operating temperatures

The operating temperature range of NiCd battery is between -50°C to 60°C, the battery capacity drops to half its value at -50°C. This performance feature is desirable in PV system locations where battery will be subjected to extreme temperatures.

3.1.1.5 Cycle life

Photovoltaic battery is expected to give a long life with a daily shallow charge/discharge cycle. In addition, seasonal variations characterized by periods of low and high levels of insolation expose a battery to gradual discharge and slow recharge cycles. Such arduous conditions often lead the battery to deep discharge beyond anticipation during low insolation period causing some damage. Some reserve capacity is therefore required while sizing a PV battery.

Oversizing is eliminated in NiCd battery, as it can effectively operate even at low SOC owing to its constant

discharge characteristics. Fully discharged or overcharged batteries do not suffer permanent harm. The phenomenon of stratification by which an electrolyte in lead-acid battery becomes denser at the bottom on repeated low rate charge/discharge cycle resulting in positive plate corrosion, is avoided in NiCd battery.

3.1.1.6 Maintenance

In a vented type NiCd battery topping up with water is required about every 10 years, while the `maintenance-free' sealed type offers a life-time of 20 years. The NiCd battery is thus suitable for remote PV installations on account of its minimal maintenance requirement.

3.1.1.7 Ruggedness and reliability

The battery by the very nature of its construction offers durability during storage, transit and installation. It does not have a `sudden-death' failure mode often observed in a lead-acid battery which is caused by one of its internal components degrading to an extent of its complete failure or breaking resulting in a short-circuit within the cell. The number of failures per hour for lead-acid battery is 100 times more when compared with NiCd battery (12). The use of a voltage regulator is not so critical with NiCd battery in PV applications on account of its ability to withstand overdischaring, under and overcharging.

3.1.1.8 Memory effect

A disadvantage associated with its performance is the 'memory effect' whereby due to repeated use in the same way, the battery adjusts itself to a certain capacity in relation to its load. As per reference (12), the memory effect applies only to a sintered-plate battery type and not to the pocket-plate type.

3.1.2 Cost consideration

Although the NiCd battery is promoted as a serious alternative to lead-acid battery in PV applications, yet its cost per ampere-hour of capacity is considered as a disadvantage for a wide use.

NiCd battery promoters however emphasize that for the well engineered PV-NiCd battery system, the relative purchase price is not as high as is often assumed. Their claim is based on the following considerations (12,20):

(i) The NiCd battery has a design life of 20-25 years and can operate well in extreme temperatures. The need for an excess capacity usually 20% is not necessary as no sulphation occurs in a NiCd battery due to its ability to work at any SOC.

(ii) In certain applications e.g. street lighting, no autonomy is required, as the battery can be dee] discharged during low insolation periods. This results in lower cost of PV modules and also the battery.

(iii) Annual maintenance of NiCd battery is less costly than that of the lead-acid battery. The latter may also be

required to be replaced as many as four times through the life of the system.

(iv) At low temperatures, there is a need to keep a lead-acid battery in a high state of charge in order to avoid freezing which would make it less cost-effective than a NiCd battery.

(v) It is possible to install significantly small Ah NiCd battery to do the job. For example a 120 Ah lead-acid battery would provide the same power as a 30 Ah NiCd battery.

3.1.3 Charging of NiCd cell using PV

The variable nature of a PV power source poses severe charging conditions on the battery. The battery system should be able to charge quickly, with no risk of damage due to overcharge and can cope up with the ever changing charging current from the panel PV source.

Traditionally, NiCd batteries are charged with constant current source using two stage current controlling system, which charges at a higher rate for part of the charging cycle and then reduces the charging rate to a lower trickle charge. This technique is not suitable for the solar charging of NiCd, as it requires a reliable power source.

The typical charging cycle of NiCd cell, when charged with a constant current source exhibits a predictable voltage change over time. Initially it rises steeply after which the majority of the charging cycle is represented by a plateau.

During this time, most of the battery capacity is achieved. The battery voltage again rises up to, above through the 100% SOC. Most battery chargers or charge controller circuits reduce the charging currents at this time. Further, the battery voltage decreases primarily due to the increased cell temperature. It is important to stop the charging accurately at this stage. If the battery is overcharged at a fast rate, it heats up and very quickly destroys itself. Thus the most critical parameter, while solar charging a NiCd cell is detecting the shape of the negative voltage rise to accurately detect a fully charged battery from the one in which the negative voltage rise may be due to cloud cover, shadowing etc.

A microcomputer circuit based charge controller for PV charging of NiCd cell has been developed by the Bobier Electronics Inc., Parkersburg, WV 26101, U.S.A. (22). The model SNC-10's main function is to prevent overcharging of the battery, while promoting the fastest possible re-charging rate with the available solar generated electricity. The programme uses battery voltage changes, when charging to determine the battery SOC. By monitoring the battery voltage with time, the controller can determine the stage of overcharging thus leading to charge being terminated. The testing algorithm has an ability to factor out changes in battery voltage caused by fluctuations in PV output. Changes in battery voltage due to battery temperature rise and

internal pressure are used to determine the attainment of the over-charge condition.

Exhibits 3.2 present advantages of NiCd battery over several other options for PV applications. Exhibit 3.3a gives a sketch of vented pocket plate NiCd battery.

3.2 Nickel-iron battery

The Nickel-iron battery is characterized by great mechanical strength and long life (> 8 years), if correctly maintained. It can remain non-functional at normal temperatures for long periods in various SOCs with negligible loss of charge and no deterioration. The battery can withstand a maximum temperature of 46°C. Overcharge at normal charge rates does not affect the battery life. In addition, the high reversibility of charge/discharge reaction leading to a longer service life and a self-discharge to 1-2% of the nominal capacity at 300°K has offered Nickel-iron battery as another option to PV battery (4,24).

The battery consists of Nickel-hydrate as active material for the positive plate and iron oxide for the negative plate. The electrolyte is a solution of potassium hydroxide, to which small amount of lithium hydroxide is added. At normal rates (2-10 h), the battery offers a discharge voltage of 1.2 V. The charge voltages at 7-10 h rate are 1.5 V and 1.84 V respectively for start and finish modes.

Exhibit 3.2: Comparison of battery types commonly used with PV systems

Plate type	Lead Calcium	Lead-calcium Antimony (0.6%)	Lead-calcium Antimony (< 2%)	Nickel Cadmium
Electrolyte type	Liquid	Liquid	Liquid	Liquid
Typical DOD	50%	80%	80%	100%
Design use	Automotive	Traction	Emergency power supplies and PV	low Maintenance Needs, PV
Self-disch. Rate	Low	Medium	Low	Low
Cycle life	Low	Medium-long	Long	Long
Seal	Vented	Vented	Vented	Vented
Topping-Up Required	Infrequent	Frequently	Infrequent	Minimal
Capital cost	Low	Mid-range	Mid-range	Very high
Suitability to PV use	Not recommended	Recommended	Recommended	Highly recommended

Ref.: (23)

Exhibit 3.2: (Contd.)

System	No. of cycles	Life (years)
NiCd pocket plate	2500	25
Plante lead-acid	1000	20
Tubular lead-acid	1500	15
Industrial flat plate	1000	10
Lead-calcium	500	10-12
Sealed lead-acid (gel type)	150	4
Sealed lead-acid (glass fibre)	500	5-10
Automotive	150	3-4

Ref.: (12)

Exhibit 3.2 (Contd.)

Feature	Lead-acid	Nickel-cadmium
Type	Medium rate, deep discharge, lead-calcium grid	Medium rate, cycle service, vented pocket plate
Rated capacity at 77°F, 8 h	100-900 Ah per cell	10-400 Ah per cell
Nominal discharge cut-off voltage	1.75 V per cell	1.0 V per cell
Nominal voltage	2.45 V per cell, varies with state of charge	1.25 V per cell fairly constant with state of charge
Operating temperatures	-20°C to + 40°C	-50°C to +60°C
Available capacity against temperature (% of rated capacity)	70% at 32°F 20% at -20°F	90% at 32°F 65% at -20°F
Nominal energy efficiency	70-80%	60-70%
Nominal cycle life for* 80% discharge cycle	1000-1500	1500-2000
Nominal calendar life without cycling	10-20 years	24 years
Energy density	6-13 W h lb^{-1}	9-10 W h lb^{-1}
Required maintenance	Water replacement; charge equalisation; protection against freezing and temperature extremes	Water replacement; occasional full discharge
Charge control	Sensitive to overcharging	Can accept 5-10% overcharge
Hazards	Electric shocks; hydrogen gas evolution; acid leaks or spills	Electric shocks
Cost (1979)**	US$165-250 kWh^{-1}	US$300-1000 kWH^{-1}

Ref.: (4)

* The nominal cycle life for lead-acid batteries is the currently available battery value for grid-connected PV systems (with frequent battery cycling).

** The 1979 cost is included for comparison only; actual prices fluctuate widely.

The battery has a disadvantage of low capacity at lower temperatures and a high weight to ampere-hour capacity ratio, as large plate size is needed for a given storage capacity.

3.3 Advanced batteries

Advanced aqueous (ambient-temperature) and non-aqueous (high temperature) batteries are under intensive development for utility energy storage and electric vehicle propulsion. Development goals aim at superiority over lead-acid batteries in terms of lifetime (> 2500 cycles), efficiency (> 70%), cost (30 $ kWh) and energy density. These goals also apply to PV applications which include both utility energy storage in the form of grid-connected PV power stations and electric vehicles being powered by PV.

Non-aqueous systems include sodium-sulphur and lithium-iron sulphide battery systems. They have an operation similar to the lead-acid battery, except that the active electrode materials are liquids which must be kept hot (200-450°C) to retain their shape and maintain good electrical conductivity. Although the volume of such batteries is equal to that of lead-acid batteries, their weights offer ease in installation and stacking. Apart from their light-weight, the advantages of absence of hydrogen and an independent temperature control system eliminate the need for ventilation. The variation in ambient temperature is also not critical for battery performance.

3.3.1 Sodium sulphur battery

The sodium-sulphur battery system offers many characteristics, which make it suitable for PV systems applications (25). However, the typical operating range of the battery is between 300 to 350 $^{\circ}C$ in order to maintain the sodium, sulphur and reaction products in liquid forms and to obtain adequate electrolyte conductivity (4,8). These temperatures present special problems in the areas of corrosion and thermal cycling. The battery needs to be installed in an oven to keep the required level of temperatures.

The battery uses molten sodium and molten sulphur-sodium polysulphide as active materials for the positive and negative plates respectively. The electrolyte is solid ß-alumina. Advantages offered by the system, which make it attractive for PV applications are the following (4):

* No electrode degradation due to shape change
* No self-discharge occurs
* Completely sealed construction
* High energy efficiency (85%)
* High energy density (theoretically 4.3 times more than that of lead-acid system)
* High rate charging capability.
* Capability of quick responses to sudden changes from charge to discharge conditions and vice versa, as well as sudden changes in load demand and in generating power.

* Well insulated system unaffected by the changes in ambient temperatures.
* Long life and minimal maintenance requirements.

Exhibit 3.3b presents sectional view and charge/ discharge characteristics of sodium-sulphur battery.

3.3.1.1 Conceptual design of a stand-alone PV power system using sodium-sulphur battery

A typically designed stand-alone PV electrical power system (~ 15 kW) incorporates about 1400 sodium-sulphur cells of high energy configuration with a total rated electrical energy capacity of 1.0 MWhe. The cells are connected in parallel (18 cells per module) and modules (78 modules per battery) are connected in series to provide a minimum discharge voltage of 120 V. The normal operating mode of the battery in stand-alone system is to provide power during an overnight operation, with a full recharge possible the following day. The battery is sized to provide power for 2 continuously cloudy days. It can recover its full charge in 2-5 days following a 100% discharge density cycle. Battery life is expected to be about 10 years (8).

This battery is highly suitable for an electrical vehicle, a solar powered one, and for utility load levelling operations.

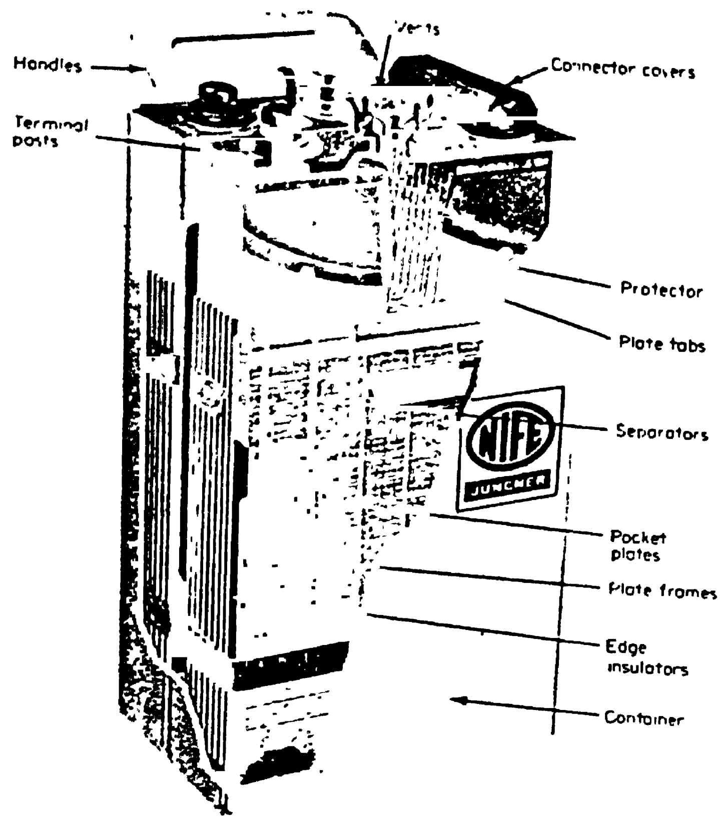


Exhibit 3.3a : Vented pocket plate NiCd battery (Ref. 34)

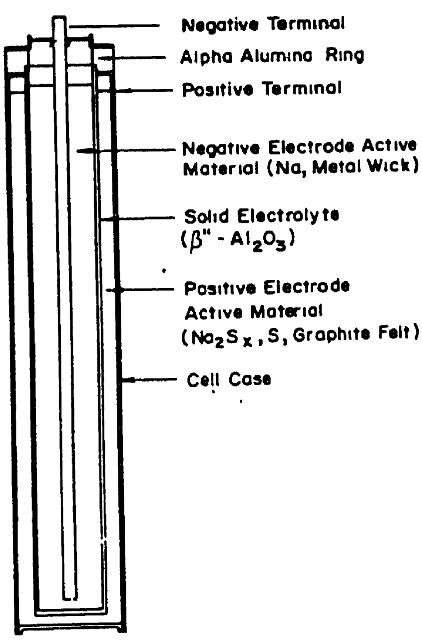


Exhibit 3.3b : Sectional view of sodium-sulphur battery (Ref. 4)

3.3.2 Lithium-iron sulphide battery

Lithium-iron sulphide battery operates between 400 and 500°C and uses a molten-salt electrolyte which is a mixture of Licl and Kcl. High power densities (~ 200 W/kg) are achieved at such high temperatures.

The Li/FeS_2 cells consist of an Li-Al or Li-Si negative electrode and an FeS or FeS_2 positive electrodes, a separator to provide electrical isolation to electrodes and Licl-Kcl electrolyte.

The open-circuit voltage of Li-Al/FeS cell is 1.34 V and is a function of both temperature and state of charge. The operating voltage is in the range of (1.1-1.3). The capacity of the cell decreases with increasing discharge rates. The self-discharge rate at the operating temperatures is remarkably low. It has a cycle life of up to 1000 cycles and end-of-life defined as a 20% loss of capacity. The cell offers an energy efficiency value in the range of 80-85% for a 4 h discharge rate, which remains constant throughout the useful life of the cell.

A lithium ion rechargeable battery giving an energy output of equal to 2.8 times the Ah capacity of a NiCd battery of same dimensions and operating voltage is reported to have been developed by Nagaura et. al. of Sony Energytu Inc. Koriyama, Japan. The self discharge of the battery being half that of a NiCd battery (26).

A recent report by Frost and Sullivan, international market research firm highlights the growing market trends for lithium batteries. According to the study, the market for rechargeable NiCd cells as a power source in several professional applications could be transformed, if a suitable rechargeable lithium cell is launched (27).

3.3.3 Zinc-bromide battery

Zinc-bromide battery is another promising aqueous secondary system for remote area power supplies using PV owing to inherent chemical simplicity, good electrochemical reversibility of the electrodes, ambient temperature operation, good energy density and low-cost material (8,28). Special features which make a zinc-bromine battery most attractive for remote area power systems including PV applications are:

* It can be repeatedly deep discharged (100% depth) without performance deterioration.
* Battery cycle life is unrelated to the current producing reactions occurring at the battery electrodes, thereby giving a battery life of up to ten years.
* It has unlimited shelf life.
* Modular construction is possible leading to the production of application specific battery.
* Energy efficiencies are high roughly (65-80%).

The inherent problem of dendrites formed by zinc electrode, thus introducing the danger of shorting and poor

coulombic efficiency are taken care of in the newly developed system based on redox flow cell using zinc-bromide both as a anolyte and catholyte (29).

The battery essentially consists of a flow cell through which an aqueous solution of zinc bromide is circulated from each of the two separate tanks, meant for anode and cathode. The overall reaction is:

$$Zn(S) + Br_3^- (aq) \longrightarrow Zn^{+2} (aq) + 3Br (aq)$$

The service life of the battery depends on long-term stability of battery components e.g. electrodes, cell frames, piping etc. Two critical factors are the separator life and long-term stability of the bromine complexing agent. No life limiting decay mechanisms have been observed in these systems. Charge control in the zinc bromine battery is simple requiring only a constant current supply with a timely cut-off.

An effort worth mentioning in the direction of developing zinc-bromine battery for PV applications is of Energy Research Corporation in the US and ZBB, (Australia) Ltd. in association with Murdoch University in Australia (30). The battery reportedly under development uses bipolar sheet electrodes made from a proprietary carbon plastic material. One side of this sheet is bonded to a high surface area carbon felt, on which the bromine reaction occurs and the zinc action occurs on the opposite side of the sheet. The sheet is bonded to a PVC frame, which is equipped with

channels through which the battery electrolyte enters and exits the battery. A porous plastic separator is used to separate the anode and cathode compartment of each cell of the battery.

The charge and discharge curve of the battery is quite flat and coulombic and voltaic efficiencies are high. The energy efficiency including pump power loss is 67.70%.

Exhibit 3.4 presents characteristics of various batteries suitable for PV applications.

Exhibit 3.4 : Characteristics of various batteries

Battery	E°/V	Energy density (Wh/kg) Theoretical	Present (5 hr. rate)	Cycle life
Nickel-iron	1.37	267	30-45	1000
Zinc-bromine	1.83	428	65-85	300
Sodium-sulphur	2.08-1.75	763	80-100	300
Lithium-aluminium iron disulphide (high temperature)	1.8	650	140-160	300

Ref.: (28)

4.0 Battery Installation, Operation and Maintenance

In order to investigate the "Battery charge control and management in PV systems", Commission of European Community (CEC) initiated concerted efforts in 1987 in this direction. The objective of the work was to identify the battery operating problems based on experiences with sixteen PV power plants (31,32).

The main problems found in these studied plants were due to:

(i) poor operation and maintenance procedures

(ii) an inadequate battery charging system

(iii) improper sizing of battery

(iv) inadequate information on the condition of batteries.

In several PV plants, batteries were found to be damaged due to deep-discharge, aging and structural failure of cell casing. A few cases of excessive overcharging and large number of operating cycles in five years of their operation were observed. In addition to these, cases of explosions caused by a build-up of Hydrogen in the cells were also observed.

The investigation revealed that in most of the studied plants, the O&M procedure was not documented and routine tests of voltage, temperature, specific gravity and periodic visual inspections were not carried out. Some of the observed problems could have been detected and avoided, if proper O&M procedures were adopted.

Several other studies have also reported the significance of adequate management of battery storage in PV installations. One such study emphasizes the need to install peripheral components for the acquisition and processing of battery specific parameters in addition to adopting active measures for battery management (33).

The following sections discuss battery installation, operation and maintenance procedures specific to PV applications.

4.1 Stresses and problem areas

The battery in PV installation is subjected to two distinct cycles viz.,

* daily cycle characterized by varying profile and amplitude depending upon the PV energy supplied and electrical energy given to the load
* seasonal cycle depending on the variation in average insolation during the year.

These cycles cause several stresses and aging mechanisms in the battery. The most commonly observed problem areas are:

4.1.1 Overcharging (grid corrosion)

Overcharging the battery causes corrosion of positive grid plates as well as excessive gassing resulting in loosening of the active material. This loosened material deposits as sediment at the bottom of the cell. Overcharging may also cause temperature rise to a permanently destructive level.

4.1.2 Undercharging (buckling of plates)

Consistent undercharging of the battery leads to a gradual running down of the cell, which is indicated by the decreased specific gravity readings and the tendency of plates to become light coloured. Excessive undercharging also causes sedimentation of white lead-sulphate powder. The strain on the plates caused by the lead sulphate, which occupies more space than the original active material on the plates results in their buckling.

4.1.3 Corroded terminals

Presence of non-conducting materials, which form a layer between the battery terminal and the connector may offer an increased resistance to the passage of large currents through the load. However, this may not ordinarily interfere with the charging of the battery or with the discharging at low discharge currents.

4.1.4 Short-circuits

Short circuits may be caused by a breakdown of separators, excessive sedimentation, due to a phenomenon called 'treeing', in which tree like structures of lead are formed from the negative to positive plates. Treeing may be due to the presence of certain materials in the grid e.g. cadmium. It may also be due to 'mossing', in which the sediment brought to the surface of the electrolyte by the gas settles on top of the plates leading to the formation of bridges over the separator tops.

The short-circuit within the battery is indicated by a rapid loss of capacity after a full charge, low battery V_{oc} and continued low readings of specific gravity, even though the battery is receiving normal amounts of charge.

4.1.5 Sulphation

When a battery is operated either at partial SOC for several days without equalization or it remains unused for any length of time in fully or partially discharged conditions, the deposition of large lead sulphate crystals instead of normal tiny ones on the plates takes place. The phenomenon called sulphation also occurs, when there are temperature variations in the battery. These large crystals tend to increase the internal resistance of the cell, which results in low discharge and high charge voltages.

4.1.6 Water loss

When the battery reaches full charge, the rise in plate potential beyond a certain cut-off voltage leads to the decomposition of water in hydrogen and oxygen gas. The quantity of gas formed depends on the amount of excess charging current which is not absorbed by the battery.

4.2 Installation

Battery (conventional flooded type) meant for PV applications is recommended for installation in a separate room in order to avoid accidents due to formation of hazardous gases. Adequate ventilation and moderate temperature is essential in accordance with the supplier's

instructions. They are most commonly designed for floor placement over wooden or plastic planks. In some cases, installation is also done on steel step stands having acid resistant paint on them (34).

Sealed maintenance free battery, on the other hand, can be housed in a usual working area with normal ventilation. It can be installed on slotted iron racks.

Although the battery suppliers recommend specific installation guidelines including battery room designs based on the type and construction of supplied battery, yet the standard guidelines for installation and maintenance of lead-acid battery for PV applications and of NiCd battery for generating stations and substations are available from IEEE in the form of American National Standards. These standards describe in detail the safety precautions, installation and design criteria, installation procedures and maintenance requirements (35,36).

Subsequent sections discuss these standards briefly.

4.2.1 IEEE recommended practice for installation of lead-acid batteries for PV systems

4.2.1.1 Safety

The safety practices listed below should be followed during the installation of lead-acid battery for PV applications.

(i) Protective equipment for safe handling of battery as also for the protection of personnel should be available. The equipment includes:

* goggles or shield for full eye protection
* acid-resistant clothing, gloves, aprons and overshoes
* portable or stationary safety shower and eye wash stations
* suitable acid-neutralizing agent
* lifting devices, tools with insulated handles
* class C fire extinguisher.

(ii) Electrolyte hazards due to corrosive and conducting electrolyte should be avoided by wearing full eye protection and protective clothing, washing the affected skin immediately, neutralizing the spilled electrolyte and properly disposing of the unused electrolyte and electrolyte containers.

(iii) Electrical shocks and short-circuit hazards should be avoided by using tools with insulated handles, removing watches and other metal objects from the body of the operator and wearing rubber gloves. In addition to these, charging source and load should be disconnected prior to opening or closing of any battery connections. Contact with any electrically conductive path of a grounded battery may result in an electrical shock.

(iv) Following precautions should be taken to prevent fire-hazards due to generation of hydrogen gas and production of high current:

* adequate ventilation should be provided and smoking prohibited in area around the battery which should also be kept free of any open flame or arcing

* static electricity from the body should be discharged before touching batteries by touching a grounded metal surface initially
* flame-arresting vents should be used, if possible
* while installing, connecting and using any auxiliary equipments such as hydrogen recombiners, manufacturer's specifications should be strictly followed

(v) Handling hazards should be avoided by taking precautions against impact of cell causing damage, excessive tilting of cells causing electrolytic spillage etc. All cell openings should be caped. In case of rack mounting, racks should be completely assembled and tightened prior to loading of the cells.

4.2.1.2 Installation design criteria

The general criteria followed for all photovoltaic battery installation is categorized into those concerning enclosure, support structure, electrical and seismic stages

1. **Enclosure**: The battery enclosure (which may vary from a box to a room size) should be located as near the array, the load and the power conditioning equipment as possible. The enclosure location should be free from any vibration and should preclude contamination of water supplies and damage to equipment in the event of electrolyte spillage. The enclosure should allow sufficient space around the battery to provide access for the installation and maintenance. In addition, it should be adequately ventilated and free from localized heat

sources, which lead to considerable temperature differences between the cells within the battery. The enclosure should be properly illuminated especially during the time of maintenance.

2. **Support structure**: Support structures, racks or other designs, must provide suitable strength to support the battery and enough space for its maintenance. It should be resistant to the effects of electrolyte, provide electrical isolation to the battery and minimize temperature differentials. The design should have sufficient space between the batteries for air circulation.

3. **Electrical**: While installing the battery, following considerations should be attended to:

(i) insulation of bare terminals, lugs and fittings

(ii) cabling should not obstruct access space provided for the maintenance

(iii) adequate overcurrent protection and timely disconnection for both positive and negative terminals

(iv) essential instruction and alarm functions.

4. **Seismic**: Battery should be installed in a manner so as to resist damage from the seismic events, if the location is prone to a high probability of seismic disturbances.

4.2.1.3 Installation and initial charging procedures

On receiving, the batteries should be inspected for any possible damage in the transit, the consignment should be

unpacked as per the manufacturer's instructions and electrolyte levels should be checked.

In case battery storage is required before their installation, then care must be taken to keep them in a cool and dry place thereby avoiding exposure to temperature extremes.

The general practice followed for battery mounting and connections is as follows:

(i) Battery should not be slid across rough surfaces nor lubricated to aid sliding. It should be placed onto the support structure starting at the centre of the lowest level and working outward and upward thus maintaining the recommended spacing.

(ii) Any area showing corrosion, dirt or acid should be cleaned.

(iii) Flame-arresting vènt assemblies, if used should be installed.

(iv) Cables should be bent before connecting to reduce stress on terminals

(v) All series interbattery connections should be made prior to parallel connections

(vi) Voltage and polarity checks should be done.

(vii) It is advisable to measure and record interbattery connection resistance to determine the adequacy of the initial installation and also as a reference for future maintenance.

To ensure that all cells are equally charged, the initial charging procedure is recommended. The preferred method is to charge the battery at a constant voltage in accordance with the manufacturer's recommendations.

The charging current and the temperature while charging should not exceed the manufacturer's specified limits. Completion of charge may be determined by measuring the specific gravity of all cells. The volumes corrected to 77°F (25°C) should be within the specific gravity range marked or engraved on the name plate and should remain unchanged for three consecutive hours.

System connections should be completed, when all the installation procedures have been satisfied.

4.3 Maintenance

Life of a battery depends to a large extent, on its proper maintenance by the skilled personnel. A good maintenance programme also serves as a valuable aid to determine the need for battery replacement.

While maintenance procedures for a battery are generally available in the literature and also from the supplier, IEEE has specifically recommended maintenance programme for both lead-acid and NiCd battery systems used in PV applications.

4.3.1 For lead-acid battery system

The entire maintenance procedure is categorized into Inspection and Corrective action, and is presented in exhibit 4.1.

4.3.2 For Nickel-cadmium battery

Safety precautions followed for battery maintenance are similar to those followed for a lead-acid battery (36). Inspection and corrective actions are presented in exhibit 4.2

4.4 Battery protection and regulating circuits

Proper battery operation in a PV system requires voltage-regulating protection circuitry to prevent overcharging and excessive discharging. Permanent damage can be done to a battery, if it is charged too fast and for too long. Similarly, forcing higher charging currents into a battery when it is fully charged will cause battery to gas. Excessive discharging will cause the plates to disintegrate and should be avoided. The use of voltage-regulating circuits to maintain the battery voltage within an acceptable range or window is therefore necessary. Generally, at any time t, the regulation process allows the determination of the state of the system which is subsequently used to issue specific commands directed at optimizing the energy transfer function within the system with respect to the constraints.

The energy flow within a simple PV system can be described by two main operating modes:

INSPECTION

INITIAL READINGS

*Battery trmnl V & cell Vs

Cell electrolyte levels

*Internal temp for minimum 10% of the cells

*Sp.gr. reading of each cel corrected to 77 F (25 C)

All connection resistances
*same for 10% sample

* REPEAT QUARTERLY

MONTHLY

General appearance & cleanliness of battery & its area

Battery trmnl V & charging current

Electrolyte levels & leakages, if any

Cracks in battery cases

Corrosion at connections

Ambient temps

Condition of ventilation system

Pilot cell voltage, sp.gr. & electrolyt temperature

Current leakage to ground

ANNUALY

Tightness of all bolted connections

All connection resistances

Integrity of battery support structure and enclosure

SPECIAL

(in case of severly discharged, overcharge and unanticipated temperature excursions)

All quarterly checks

Detailed visual inspection

CORRECTIVE ACTIONS

(to be corrected at the time of inspection)

low electrolyte levels by adding water, only when cells are in fully charged conditions

high connection resistances by disassembly, cleaning and reassembly

deviation in cell temperatures by more than 5°F (3°C) from each other

battery temperature outside the system design limits

excessive dirt or spilled electrolyte

fully charged battery voltage outside the manufacturer's recommended range

equalizing the charge when
- sp. gr. corrected for temp & electrolyte level, of an individual cell is more than 10 pts (0.01) below the average of all cells
- same, if found 10 pts below the average installation value
- fully charged voltage is 0.1 v or further below the manufacturer's recommended end-of-charge voltage

IEEE RECOMMENDED MAINTENANCE PROCEDURE FOR LEAD-ACID PU BATTERY

Exhibit 4.1 (Ref. 35)

INSPECTION

Monthly

float voltage measured at battery terminals
general appearance and cleanliness
charger output current and voltage
electrolyte levels
cracks in cells or leakage of electrolyte
any evidence of corrosion
operability of ventilation equipment
pilot cell electrolyte temperature

Quarterly

check and record the voltage of each cell

Yearly

cell-to-cell and terminal resistance
integrity of the battery rack

CORRECTIVE ACTIONS

(TO BE DONE PRIOR TO NEXT INSPECTION)

if any electrolyte reaches low-level line, water should be added

if the float voltage measured at battery terminals is outside the recommended value, charger should be adjusted

if corrosion, dirt, potassium carbonate noted on cells or connectors, should be wiped with wet cloth

if any resistance reading is more than 20% above the installation value, connections should be retorqued, retested and reassembled if necessary

IEEE RECOMMENDED MAINTENANCE PRACTICE FOR NiCd BATTERY

Exhibit 4.2 (Ref. 36)

(i) Floating operation condition, when battery voltage fluctuates between maximum and minimum voltage levels corresponding to a maximum and minimum SOC of the battery. The system is autoregulated during the day and, the battery discharge through PV modules in the night is protected by a diode.

(ii) Overcharge and overdischarge conditions, for which system regulation requires information on battery voltage and acceptable extreme values (V_{max} and V_{min})

Exhibit 4.3 (a-b) show some of these circuits. The basic components in all these designs are an array, the battery and the voltage and/or current regulating battery protective circuitry.

In 4.3a, the battery protecting regulator devices are in series with the array and the load. When battery voltages becomes too high, the overvoltage (OV) regulator sheds part of it or all of the array to reduce or stop the charging current. Alternatively, when the battery voltage and charge drop to a relatively low level, the regulator adds all or part of the array to the system circuit.

The undervoltage (UV) regulator disconnects the load, when the battery charge and voltage are below the minimum acceptable level. In the event of load cut-off, the array is also disconnected from the load and is only allowed to charge the battery. When the battery voltage reaches its permissible level, the undervoltage regulator connects the load (37).

Another circuit shown in 4.3b has the battery-protection circuitry arranged in such a way so as to allow a permanent and direct connection between the array and the load. The UV regulator is placed in the battery branch of the circuit. When a low battery voltage causes the regulator to disconnect the load from the battery, the diode wired across the regulator would still allow the array to charge the battery. The OV regulator shunts current away from the battery, when its voltage rises too high. An innovative design would also incorporate a variable current shunt, which can be created using a bank of resistors connected in parallel with the array via relays or a linearly integrated circuit device biasing a transistor, which in turn directs the current through one or more of the resistors.

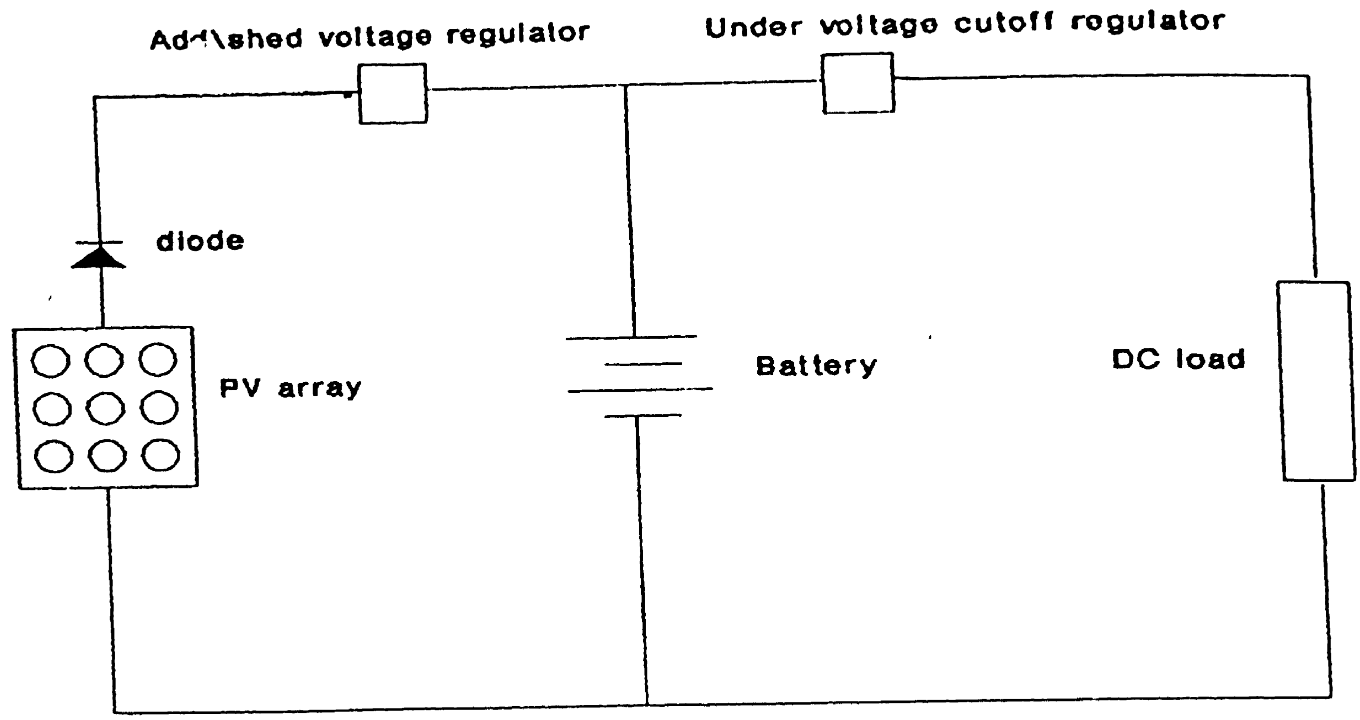
Excess array power in both these circuits is either dumped into a bank of resistors or is disconnected. This power can be put to a good use by switching on some intermediate loads.

A brief description and circuit diagrams of the following regulators are given in exhibit 4.4a-d (4). (i) Shunt regulator

(ii) Series regulator with semiconductor

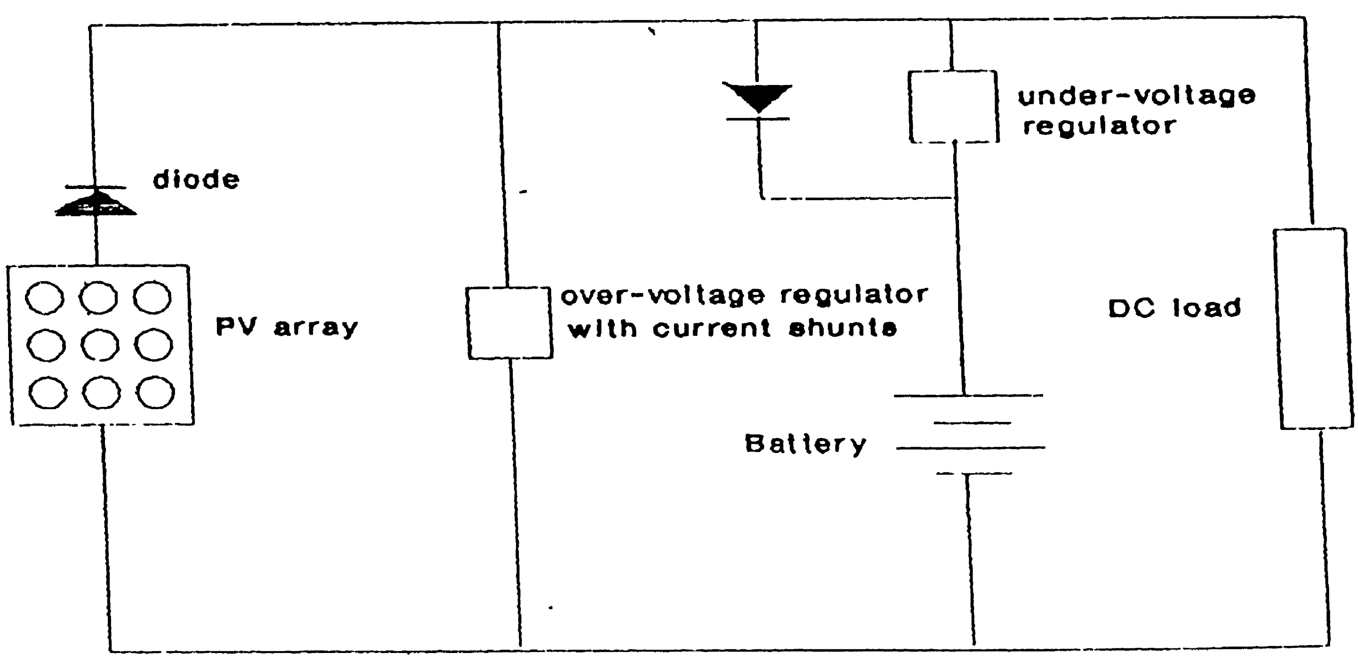
(iii) Series regulator by electromechanical cut-off

(iv) Automatic circuit breaker.



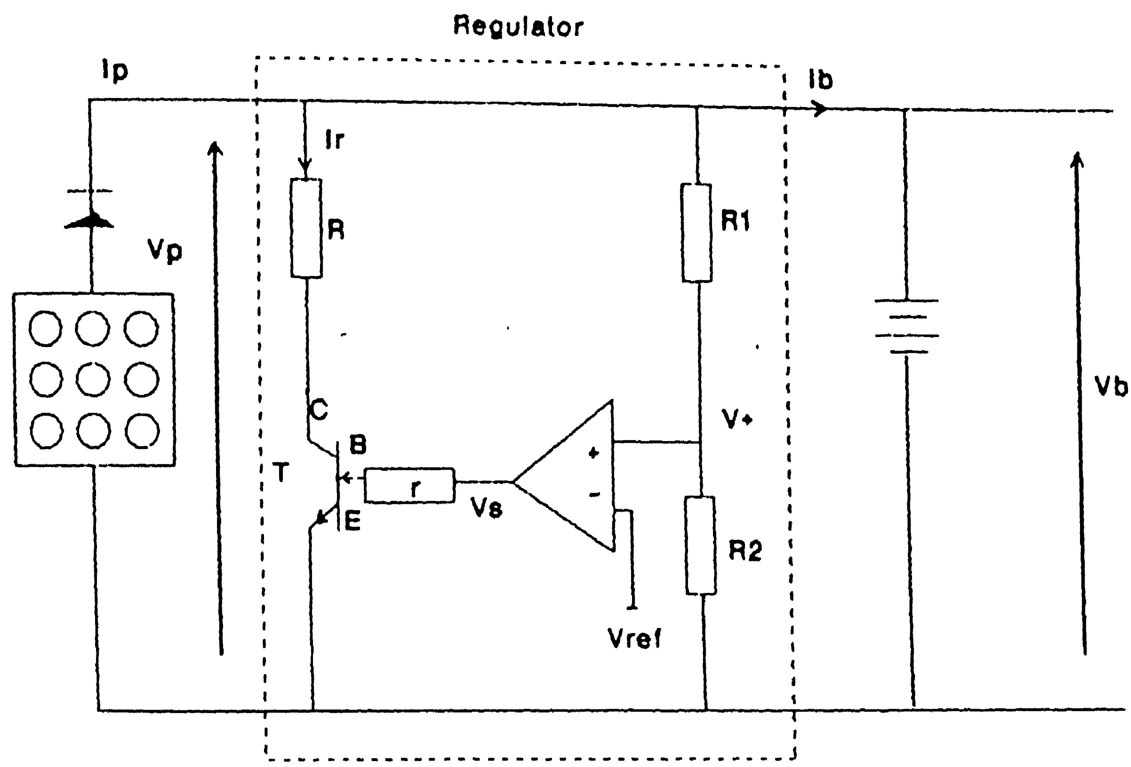
Battery storage with add\shed voltage regulator

Exhibit 4.3 a (Ref. 37)



Battery storage with current shunting overvoltage regulator

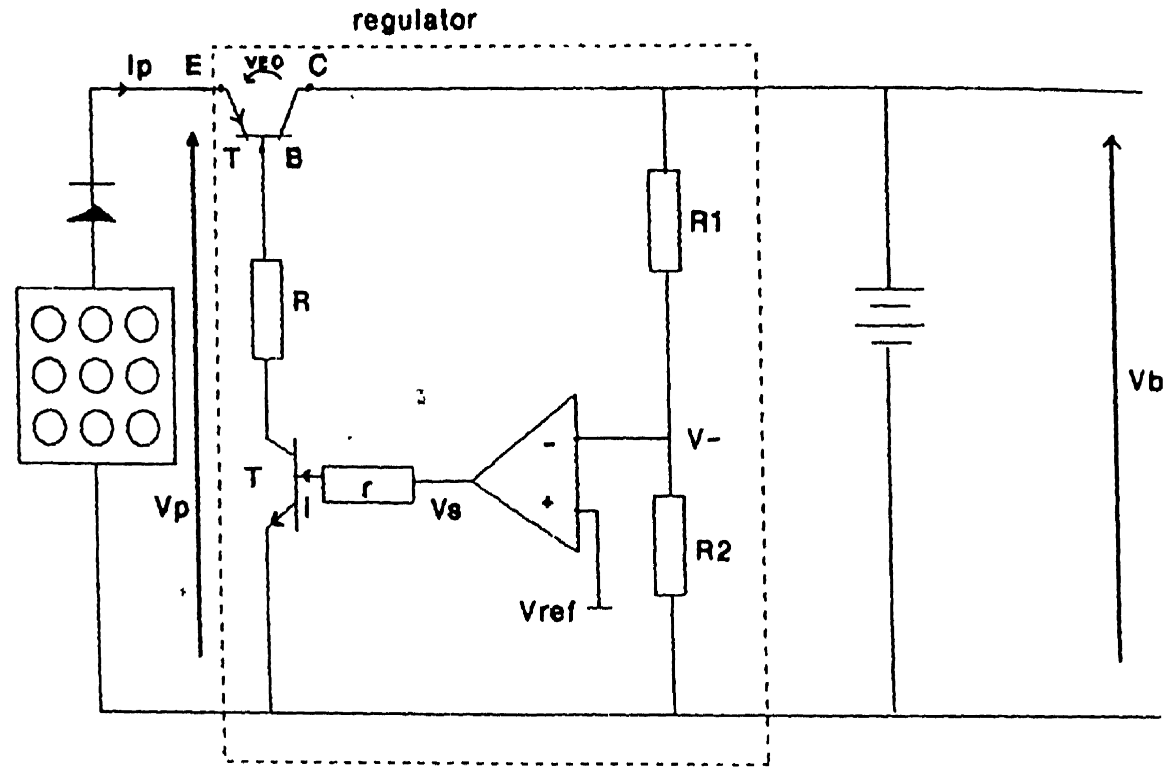
Exhibit 4.3 b (Ref. 37)



Shunt regulator

The regulator which is connected in parallel to the PV generator dissipates excess energy through a resistor and power components. There is no voltage drop in the charging unit and the power consumption by the regulator is negligible during the non-regulation period. Any failure in the regulator does not interrupt the battery charging.

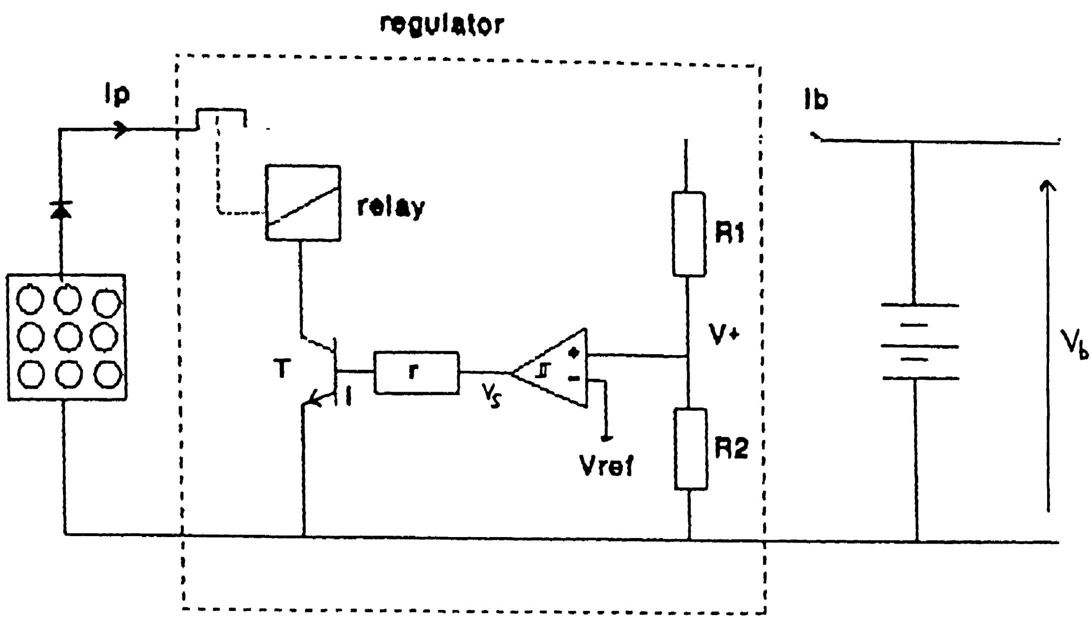
Exhibit 4.4a: Shunt regulator (Ref. 4)



SERIES REGULATOR

The series regulator uses a transistor in series with the PV generator. The regulator behaves like a variable resistance, whose value is a function of the SOC of the battery. The dissipated power at the transistor terminals is low compared to PV peak power. However, during non-regulation period, the regulator introduces a voltage drop and thereby a current consumption in the circuit.

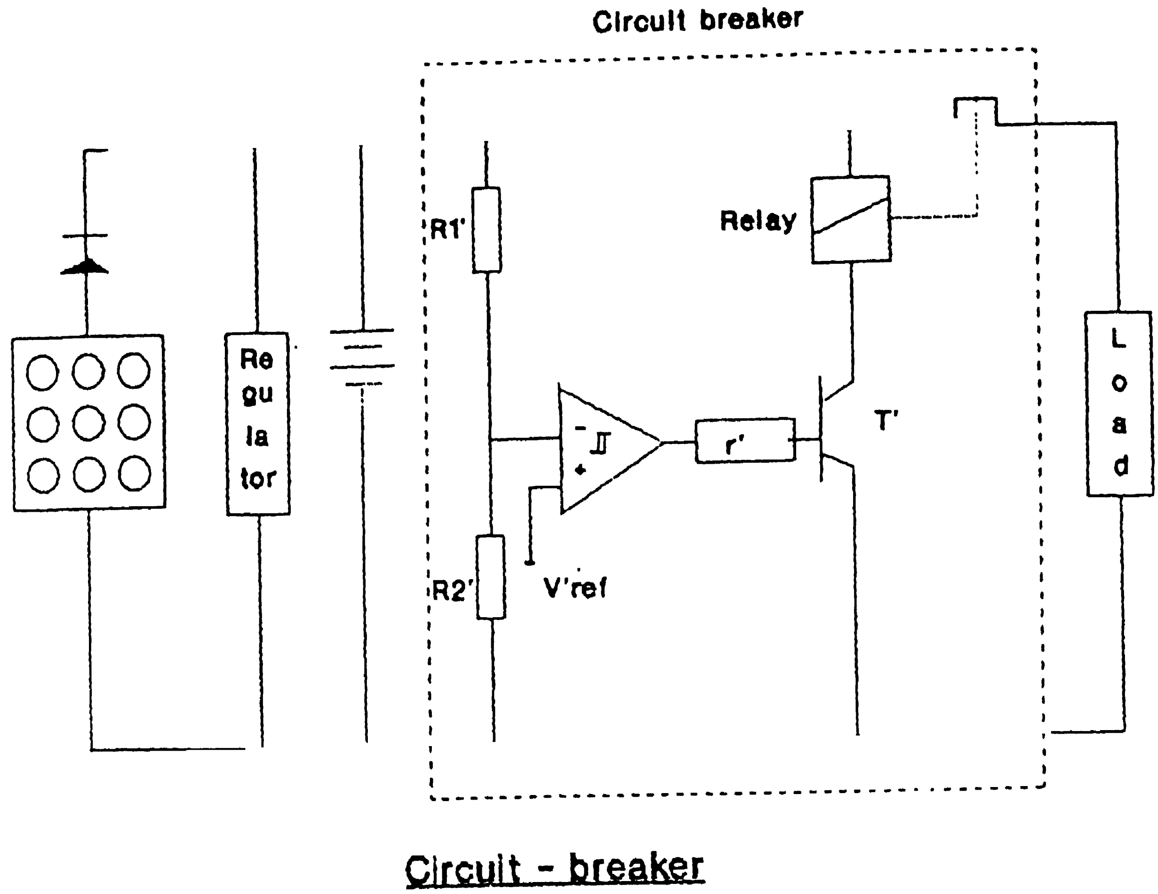
Exhibit 4.4b: Series regulator with semiconductor (Ref. 4)



Series regulation by electromechanical cut-off

This regulator stops the battery charging by an electromechanical cut-off, when it reaches the maximum acceptable voltage level. It is reset for charging automatically, when the threshold voltage is reached. There is no power dissipated in the regulator.

Exhibit 4.4c: Series regulator by electromechanical cut-off (Ref. 4)



The regulator is used in cases of weak sunlight, over-consumption etc., when it becomes necessary to cut-off the load to limit the depth of battery discharge. Below a certain threshold voltage level, the load is cut-off and is reset automatically, when the battery reaches a sufficient charge level.

Exhibit 4.4d: Automatic circuit breaking (Ref. 4)

5.0 Characterization and Testing Methods

Many specifications and performance standards are used to evaluate battery performance and measure battery power. In the United States, Battery Council International and Society for Automotive Engineers established accepted capacity, cycle life and vibration tests for SLI or automotive batteries. These test standards are regularly updated. International Electrotechnical Commission co-ordinates similar standards worldwide especially for an European market. The current section describes characterization and testing procedures specifically used for PV or a solar battery. The characterization test programme is based on ERA test regime. Currently TATA BP SOLAR Batteries are characterized using this progamme (38). The test procedure adopted for low-water-loss and SLI battery is taken from reference no. (4), while those for NiCd battery is recommended by the IEEE (36).

5.1 Characterization test programme

Exhibit 5.1

5.1.1 Battery conditioning test

Test Specification - Test gravity - 1.240 @ 27°C

Acid level - `0' level

Test sequence - 10 cycles of charge and discharge

- Discharge @ 0.2 C_5 for 4 hrs

  Charge @ 0.155 C_5 for 8 hrs

  Capacity test @ C_5 twice on fully charged batteries

  Discharge current - 0.2 C_5 amps

  End voltage - 1.67 V/cell

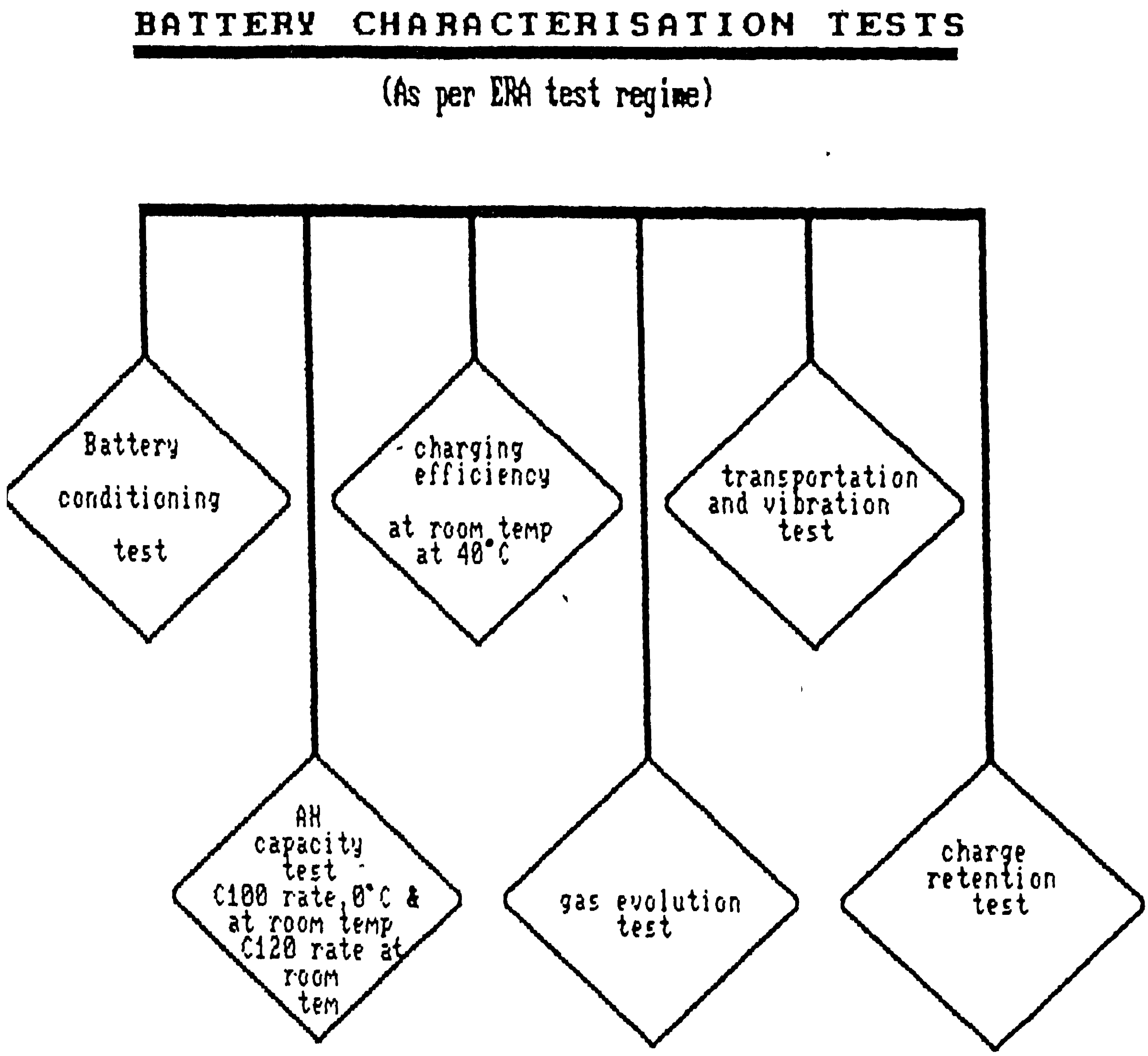


Exhibit 5.1 (Ref. 45)

Description The test schedule should consist of 10 charge/discharge cycles as under.

Charge - 0.115 C_5 for 8 hrs

Discharge - 0.2 C_5 for 4 hrs.

Capacity measurement needs to be carried out at a nominal 5 hrs rate.

5.1.2 Ampere hour capacity test

Test specification - Acid gravity - 1.240 @ 27°C

Acid level - `0´ level

End voltage - 1.8 V/cell

Test sequence

(a) Fully charged battery discharged @ C_{100} at 0±1°C temperature

(b) Fully charged battery discharged @ C_{100} at room temperature

(c) Fully charged battery discharged @ C_{120} at room temperature

Description: Determination of Amp hr capacities

While measuring 100 hr rate capacity at 25°C, batteries at higher acid concentration should be considered. Their capacities should be recorded.

Amp-hr capacity at the 120 hr rate should be measured. Room temperature during tests should be varied between 23-29°C. The 100 hrs discharge at 0°C should be controlled to within ± 2°C and measured capacity to be recorded, without any correction.

It is necessary that the discharge current be regulated to + 0.01 A using an electronic resistor. A graph showing the voltage against discharge duration should be obtained. The end voltage shall be 1.80 V.

Amp hr capacities at 100 h, 120 h at 25°C and 100 h at (0°C) should be tabulated.

Test pass criteria - the achieved capacity should be within the limit claimed by the manufacturer

5.1.3 Charging efficiency

(A) At room temperature

Test specification - Acid gravity - 1.240 @ 27°C

Acid level - \`0´ level

Test sequence - Fully charged batteries discharged to state of charges - 80%, 90% & 95%.

Const. Voltage - 2.5 V/cell

Condition - less than 10 mA change in current per hour

Ah input to reach above condition

$$\text{Computed charge (Ah) efficiency from graph} = \frac{\text{Output}}{\text{Input}}$$

(B) At 40°C

Test specification

Acid gravity - 1.240 @ 27°C

Acid level - \`0´ level

Test sequence

Fully charged batteries discharged to depth of discharges - 20%, 10% & 5%.

Const. voltage - 2.40 V/cell

Temperature - 40 ± 1°C

Condition - less than 1 mA change in current per hour

Ah input to reach above condition

Computed charge efficiency from graph $= \dfrac{\text{Output}}{\text{Input}}$

Description

The 100 hr capacity battery should be discharged to 90% SOC (i.e. 10% discharge only). The batteries should be recharged at 40°C at a constant voltage of 2.40 V per cell, until the attainment of full charge (i.e. constant current and the gravity to be recorded).

The voltage time profile is to be plotted.

The total time taken and the Amp-hr input should be recorded. An integrating type ammeter is to be used.

The above test is to be repeated at room temperature also.

5.1.4 Gas evolution test

	Acid gravity - 1.240 @ 27°C
	Acid level - \`0´ level
Test sequence	Fully charged battery on constant voltage
	Charging voltage - 2.30V, 2.40V, 2.50V, 2.60 V per cell.
	Temperature - @ room temp. @ 40°C
	Gas collection I - when change of current is less than 10 mA hour.
	Gas collection II- After switching off charging

Description of test

Gas evolution in the fully charged condition should be measured for charging voltages from 2.30 to 2.60 V at room temperature and at 40° ± 1°C maintained by a thermostatically controlled waterbath.

Gas evolution during charging may be measured by passing it through a rubber tube and then into a graduated water filled burette, clamped in an inverted position over a water tank. The amount of water displaced is a measure of the volume of gas evolved/collected.

For this measurement, the battery should be kept on charge using a DC power supply regulated to within ± 5 mV. The current should be maintained for 1 to 2 hrs, until the change in its value is less than 10 mA. The gas flow should be measured over a period of time.

It should be noted that the normal vent plug should be replaced by a manifold for ducting. The cell voltage varies from 2.30 to 2.60 V.

Open circuit gas emission should be measured.

5.1.5 Transportation & vibration test

	Acid gravity - 1.240 @ 27°
	Acid level - `0´ level
Test sequence	Capacity test @ C_5
	C_5, 0.2 A and voltage of 1.67 V/cell
	Fully charged battery packed in transportation crate

test done at

CAM shaft speed - 120 rpm

Amplitude - 25 mm

Duration - 60 mts.

Capacity test @ C_5, 0.2 A - 1.67 V/cell

Description

The 5 hr rate capacity to be determined initially. Batteries should be loaded onto a transit - tester to simulate the road transportation condition. The bed should be vibrated at a peak to peak vertical displacement of 25 mm. (Ref. British Defence Standard 07-55 part 2, Test A 8). Any visual damage should be noticed after the test. The 5 hr rate capacity should be determined again.

Test pass criteria

(a) No spillage of acid

(b) No visual damage to the container/batteries

(c) No abnormalcy in electrical performance of the battery.

5.1.6 Charge retention test

Test specification - Acid gravity - 1.240 @ 27°C

Acid level - '0' level

Test sequence - Battery conditioning (10 cycle)

C_5 capacity test twice (I&II)

Average of C_5 (I) and C_5 (II)

Battery kept @ 40°C for 12 weeks.

C_5 (III) done at room temperature

Compute loss of capacity.

Description

The 5 hr. capacity should be measured initially. The batteries should be fully charged and then stored at 40° ± 2°C. These batteries should be kept in storage for 13 months. After this period, the 5 hr capacity is to be re-determined.

Test pass criteria

Less than 6% per month or 0.2% of capacity loss per day.

5.2 Testing low-water-loss batteries

Testing of low-water-loss batteries is a three step process as described in detail in exhibit 5.2. Step 1 is the visual inspection, to observe any obvious damage to the case, cover, terminals etc. Conditions of cables and cable clamps are also inspected. Next step is to check the electrolyte levels and battery's SOC. In most cases, depletion of reserve electrolyte volume above the plates signals the end of battery life. If in such cases, water cannot be added, then the battery needs replacement. For measuring the SOC, the battery should be kept on open-circuit condition overnight or at least for several hours so as to be assured of a stabilized open-circuit voltage reading.

Step 3 is to ensure that the battery's electrical performance is satisfactory. The procedure must be carried out only, if the battery is at or above the SOC specified in step 2.

STEP 1

VISUAL INSPECTION

Check for leakage terminal damage etc.

Cannot be used replace

No obvious damage proceed

STEP 2

ELECTROLYTE LEVELS & STATE OF CHARGE

Level at top of plates-water cannot be added

Indicator indicates low level

Replace

Stabilized voltage above 12.4 volts or indicator indicates charged

Proceed

Level OK. unknown or water can be added-Stabilized voltage below 12.4 volts

Indicator indicates low charge

Charge- then turn on high-beam head lamps (or 15 amps load for 15 s)

Proceed

STEP 3

LOAD TEST

* connect voltmeter and ampere load equal to 1\2 the cold cranking amperes @(-18°C) rating of the battery for 15 seconds
* observe voltage at 15 seconds with load on
* refer to voltage chart

Voltage below chart value

Replace

Voltage equal to or above chart value

Return to service

VOLTAGE CHART

Estimated Electrolyte Temperature °F	°C	Minimum required voltage under 15 s load (use 1\2 these values for 6 v battery)
70	21 & above	9.6
60	16	9.5
50	10	9.4
40	4	9.3
30	-1	9.1
20	-7	8.9
10	-12	8.7
0	-18	8.5

TESTING CHART FOR LOW-WATER-LOSS BATTERY

Exhibit 5.2 (Ref. 4)

5.3 Testing automotive batteries

Variety of load testers, hydrometers and voltmeters are available for testing different battery types. An adjustable-load tester and a hydrometer, which measures specific gravity should preferably be used for testing automotive (SLI) batteries. The testing procedure is presented in exhibit 5.3.

5.4 Capacity test schedule for NiCd battery

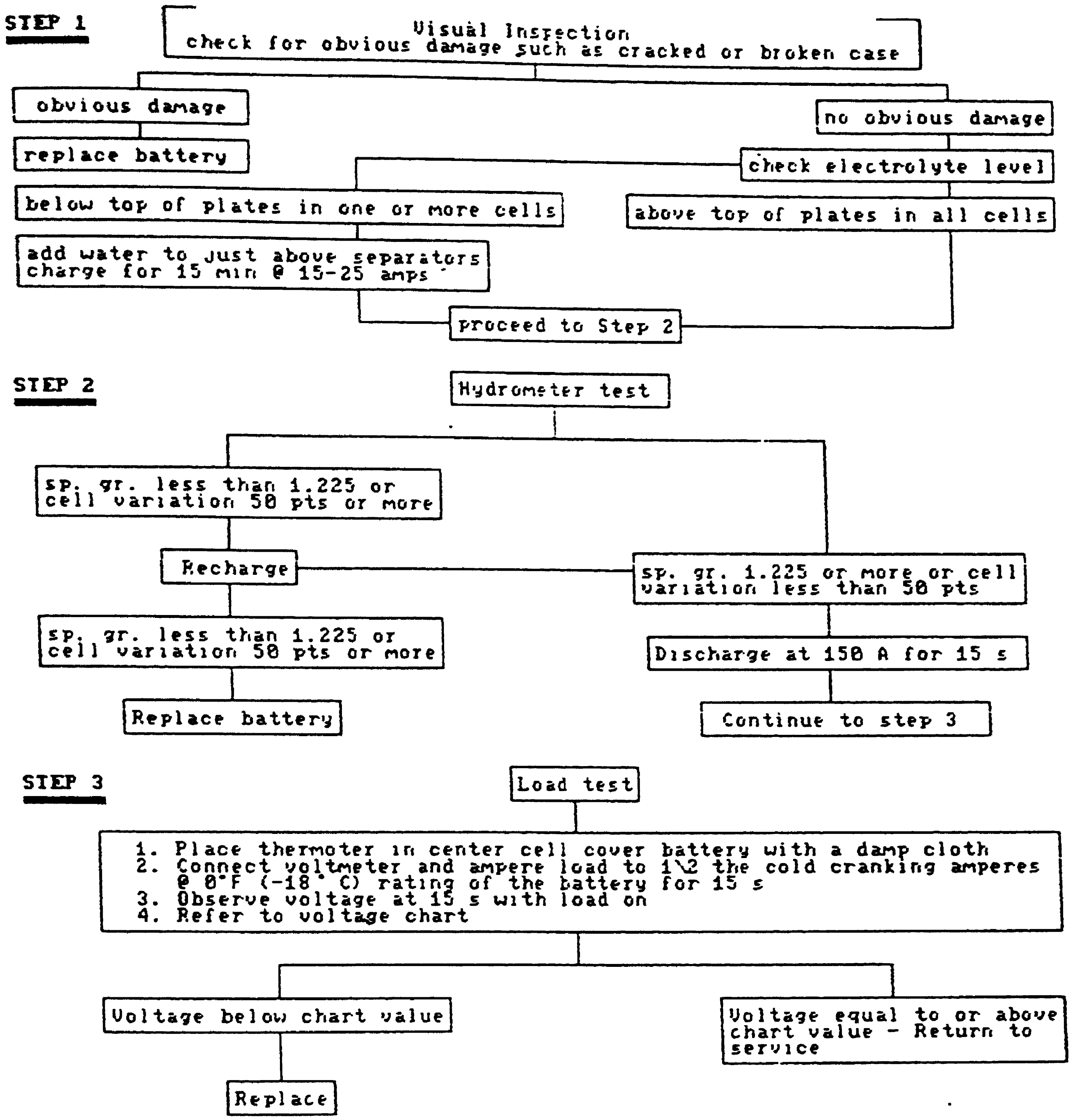
The objectives of IEEE recommended capacity test schedule are to determine:

(i) Whether the battery meets its specifications or manufacturer's ratings or both

(ii) Whether the performance of battery is within acceptable limits.

(iii) Whether the battery, as found, meets the design requirements of the system, to which it is connected.

The acceptance test for the battery capacity should be done upon initial installation, at a specific discharge rate and for a duration related to the manufacturer's rating. The performance test of battery capacity should be made within the first two years of its operation. Additional performance test for each battery may be done at a 5 year intervals, until it shows signs of excessive capacity loss. The same is indicated, when the battery capacity drops to more than 1.5% per year of rated capacity from its capacity on the previous performance test.



Voltage Chart

Estimated electrolyte temp °F	Estimated electrolyte temp °C	Minm required voltage under 15 s load (use 1\2 these values for 8 v battery
70	21	9.6
60	16	9.5
50	10	9.4
40	4	9.3
30	-4	9.1
20	-7	8.9
10	-12	8.7
0	-18	8.6

TESTING CHART FOR SLI BATTERIES WITH ADJUSTABLE-LOAD-TESTER AND HYDROMETER

Exhibit 5.3 (Ref. 4)

Annual performance tests of battery capacity should be dome on any such battery, as shows signs of excessive capacity loss.

5.4.1 Test procedure

The procedure describes the recommended practice of capacity testing by discharging the battery.

5.4.1.1 Initial conditions

The following is the set of instructions concerning battery capacity tests.

1. Verify that the battery has had a high rate charge completed for more than one day and less than seven days prior to the start of the test.
2. Check all the battery connections and make sure that all connectors are clean, tight, and free of corrosion.
3. Read and record the float voltage of each cell just prior to the test
4. Record the temperature of the battery electrolyte to determine an average temperature (every tenth cell is suggested).
5. Read and record the battery terminal float voltage.
6. Disconnect the charger from the battery.
7. Take adequate precautions (such as isolating the battery to be tested from other batteries and critical loads) to ensure that a failure will not jeopardize other systems or equipment.

5.4.1.2 Test length

The recommended procedure is to make a capacity test for approximately the same length of time as the duty cycle for which the battery is sized.

5.4.1.3 Test discharge rate

The discharge rate depends upon the type of test selected. For the acceptance test or performance test, the discharge rate should be at a constant current equal to the manufacturer's rating of the battery for the selected test. The test discharge current is equal to the rated discharge current divided by K. Where K is the discharge current correction factor for the initial electrolyte temperature as per the table below:

Table: Discharge current correction factor K for temperature

Initial temperature (oC)	(oF)	**Factor K Range**
17.8	0	1.1-2.0
12.2	10	1.1-1.6
6.1	20	1.1-1.5
1.1	30	1.1-1.3
4.4	40	1.0-1.2
10.0	50	1.0-1.1
15.6	60	1.0-1.1
21.1	70	1.0-1.1
2.5-4.5	77-115	1.0

5.4.1.4 Acceptance and performance tests

Set up a variable load with an associated instrumentation facility consisting of an ammeter, a voltmeter, and a timer. Vary the load to maintain a constant current discharge equal to the rating of the battery at the selected rate.

1. Connect the load to the battery, time the test, and continue to maintain the selected discharge rate.
2. Maintain the discharge rate, until the battery terminal voltage decreases to a value equal to the specified average voltage per cell times the number of cells.
3. Record individual cell voltages and the battery terminal voltage. The readings restricted to three sets should be taken on connecting the load initially and at intervalled steps.
4. Observe the battery for any abnormal intercell connector dissipation.
5. Finally, determine the battery capacity according to the procedure described below.

5.4.1.5 Determining battery capacity

For an acceptance or performance test, use the following equation to determine the battery capacity at the test rate. Percent capacity at the test rate at 25°C (77°F) = $T_a/T_R \cdot 100$

where T_a = actual time of test to check specified terminal voltage

T_R = rated time to check specified terminal voltage.

5.4.1.6 Service test

Service test is a special battery test, which may be required to determine the ability of the battery to meet the design requirements (battery duty cycle) of the dc system. Recommended procedure for the test is as follows:

1. The initial conditions shall be as identified earlier.

2. The discharge rates and test length should correspond to the design needs of the dc system to a practical close limit.

3. Failure to do so demands a review of its rating to see if it is properly sized. At a high rate, charge the battery, inspect it, take necessary corrective action, and repeat the service test. A battery performance test may also be required to determine, whether the problem is the battery or application related.

5.4.1.7 **Restoration**

Disconnect all the test apparatus. At a high rate, charge the battery for return to normal service.

5.4.2 **Replacement criteria**

The recommended practice is to replace the battery, if its capacity as determined indicates the remaining margin availability of an year. The timing of the replacement is a function of the sizing criteria utilized and the capacity margin available compared to the load requirements.

Failure to hold a charge, as shown by cell voltage, is a good indicator for further investigation into the need for replacement.

5.4.3 **Records**

Data obtained from inspections and corrective actions should be recorded at the time of installation and as specified during each inspection. Records should also

contain tests indicating discharge rates, their duration, and results.

The desirable preparation of the ordered data forms is recommended to facilitate comparision with previous data and thereby its conversion into a standard base favouring the manufacturer's recommendations.

6.0 Battery Modelling, Simulation and Sizing

Stand-alone PV systems with battery storage are usually designed to ensure array energy output exceeding the load demand year round. The system is also expected to maintain a continuous supply of energy for night-time loads and during cloudy days. The battery is sized depending upon the load energy requirement and weather patterns on the site. The latter one necessitating increased storage and PV capacity during the heavily overcast sky and low insolation period of the year. Consequently, during peak sunshine days, the battery will remain near a fully charge state with the array generating excess energy. It needs to be either disconnected or dissipated in order to prevent battery from overcharging. A major concern in designing any PV power system, therefore is to obtain optimum capacities of PV array and the battery storage for the supply of energy at the chosen reliability.

In order to match the battery behaviour properly with the array as well as with the load, the modelling exercise is performed. This exercise gives parameters, that characterize the battery's state; e.g. current accepted and lost, internal e.m.f., voltage or terminal voltages, state of charge, internal resistance etc. The dynamic behaviour of the system can then be simulated for any operating condition based on the developed model. The application of simulation technique in battery sizing results in an optimum battery capacity

required to satisfy the given load with an expected reliability.

Several groups of researchers have developed battery models describing the relation amongst battery voltage, current and SOC. The University of Utrecht, Eindenhoven The Netherlands, has carried out studies on models applicable for both technical design and economic analysis of PV battery system (39). The model describing a relation amongst the voltage, current and SOC of a battery is needed for its designing, while for designing the control system, a model for relating the capacity of the battery to discharging current is useful. The aging model describing the lifetime of a battery is useful for an economic analysis.

The study concluded that the Shephard's model (40) is the most applicable design model in PV system modelling.

6.1 The voltage/current/SOC model (Shephard's model)

The normalized voltage u, which is the rate of real to nominal voltage, is expressed below in Shephard's model as:

$$u = (e - C.q_d) - i.r \left(1 + k \left(\frac{q_{c,d}}{q_s - q_{c,d}}\right)\right)$$

where the parameters e,c,r,k and q_s differ from charging (subscript c) and discharging (subscript d) modes.

i is the normalized current defined as the ratio of real current to the nominal capacity in Ah.

q_c, the SOC is defined as $(1 - q_d)$, q_d being the depth-of-discharge (DOD).

6.2 Capacity model

Using Shephard's equation, the capacity of the battery can be related to the discharge current as follows:

$$C_1 = q_s/(1 + i.r.k/constt)$$

where C_1 is the capacity, which can be taken from a fully charged battery at a normalized current i. The curve fit with an empirical data using this model is found to be good for discharge currents occurring in PV systems.

6.3 Model based on loss-of-load-hours (LOLH)

The model developed by researchers at Asian Institute of Technology, Bangkok, uses LOLH concept, which expresses the number of hours in a year during which a PV battery system is unavailable to meet the load demand (41).

It is often inadequate to design the system on the basis of monthly average insolation and estimated number of no-sun days due to the dynamics of PV system and varying climatic conditions. The model therefore uses an hourly meteorological and load data to relate the system reliability (LOLH) with that of array and battery size.

The battery model considers internal charge/discharge resistance to calculate the battery SOC, which at a time (t + dt) can be computed from the previous SOC (at time t) using the following expression:

$$S_{(t + dt)} = S_t \, (1 - D_s \, dt) + K_1 \, (VI_b - K_2 I_b^2)dt$$

where

S_t = SOC of the battery at time t, (Wh)

D_s = Self discharge rate (W)

K_1 = Charge/discharge efficiency

K_2 = Charge/discharge resistance (ohm)

V = System voltage (V)

I_b = Battery current, (amp)

The battery charge/discharge voltages and resistances are updated every (dt).

6.4 Autonomy sizing

A simple way to size the battery is for an estimated autonomy, which is chosen mostly by experience. The reserve capacity often known as number-of-days is used to cover up the time between sunset to sunrise, the day to day variation in an year and the variations from year to year.

By assuming that the battery is fully charged daily, the capacity is simply calculated using the expression:

Capacity (battery): $N \times L \times K_T \times K_D \times K_a$

N = Number of days of autonomy estimated

L = Daily load

K_T = Compensation for temperature extremes

K_D = Compensation for maximum allowable depth of discharge (MDOD)

K_a = Compensation for aging

As stated earlier, this technique is a simplified one and does not consider effectively either the variation in load demand or the climatic conditions.

6.5 Availability sizing

This sizing method uses daily insolation values either constructed from monthly/daily average values or from measured ones (42). The detailed battery model includes:

* capacity derating as a function of the electrolyte temperature
* charging efficiency as a function of electrolyte temperature and state-of-charge
* charging voltage as a function of electrolyte temperature and state-of-charge.

It is possible to estimate the maintenance interval and the influence of the insolation variations and/or the battery size on the expected lifetime of the battery.

6.6 Simulation and sizing using LOLH

The simulation results for the chosen load profile present the LOLH-PV-Battery relationship on LOLH-Battery map. A combination of PV and battery for the same LOLH can be obtained from these maps using a two-dimensional inverse interpolation technique. Exhibit 6.1 presents one such map. The results are obtained in the form of the following equation, which indicates that the maximum cost to meet given reliability occurs at a point, where the price ratio P_W/P_B equals the marginal rate of substitution between PV and battery:

$$\frac{d_{Battery}}{d_{PV}} = \frac{P_W}{P_B}$$

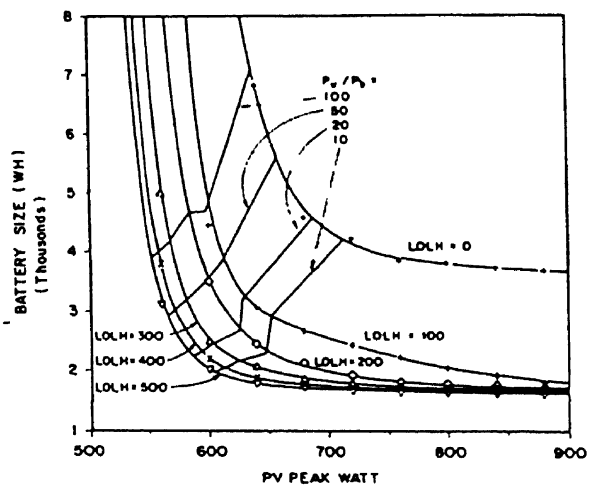


Exhibit 6.1: Iso-LOLH curves and optimum design points at four price ratios for a stand-alone PV power system (Ref. 4)

6.7 Sizing using loss-of-load-probability (LOLP)

The approach developed by Sandia National Laboratory,. Albuquerque, U.S.A. uses standard nomograms to choose array and battery size for achieving required LOLP (43).

The LOLP presents the level of confidence, at which the system will satisfy the load. LOLP values of O&I refer to the satisfied/unsatisfied load demands respectively. Storage capacity values are read from storage-sizing nomograms as a function of the required LOLP. This technique is valid for systems with a fixed tilt array and for any hourly load profile or daily load profile within a given month.

The sizing depends on an estimation of two parameters viz.,

(i) insolation to storage path efficiency (η_{in})

(ii) storage to demand path efficiency (η_{out})

These path efficiencies are the product of all involved subsystems. These efficiencies are defined as:

$$\eta_{in} = \frac{\text{(daily energy added to load)}}{\text{(daily average insolation) * (area of array)}}$$

$$\eta_{out} = \frac{\text{(demand)}}{\text{(daily energy taken from storage)}}$$

demand/ η_{out} = (daily average insolation) * Area x η_{in}

The storage capacity is defined as:

Storage = (days of storage) * (demand)/ η_{out}

The constraint with this approach is that the average monthly load must not vary more than ± 10% for month-to-month.

6.8 Limitations of mathematical modelling of lead-acid battery

Undoubtedly the mathematical models have been developed sufficiently well to simulate the battery behaviour in complex operating conditions, during recharging and discharging. However, these cannot as yet handle aging problem with a similar reliability (44). Modelling, which identifies parameters to characterize the battery's state, is not sufficient in itself so as to decide the battery design. Knowledge of battery's performance in terms of its lifetime is equally important. For example, the modelling exercise may be able to predict the corrosion current at a given voltage and temperature,but light on battery's tolerance limit can adequately be shed upon by the manufacturer only. Similarly, the model may forecast the consumption of charge in gas-bubbling and hydrolysis for SOC determination. However, only the experiences of the manufacturer and performance of any operational plant would be able to estimate reliably the amount of gassing needed to re-mix an electrolyte and thus avoid stratification, or how often it is really required to carry out complete recharging of the cells.

To summarize, knowledge of the battery's response for longer times or the deterioration, which has taken place after the battery has reached a certain state, the manufacturer's experience and an analysis of the results of operating plants are the best sources.

7.0 Commercially Available Photovoltaic Batteries

Lead-acid automotive battery has traditionally been used for photovoltaic applications. At the same time, from the view of its performance reliability. It has also been identified as the most sensitive sub-system of the entire installed system. Steady growth of PV global market and continued R&D in the area of improving field reliability of PV systems have lead to the development and commercial availability of batteries, which offer specific features desirable in a PV installation. These batteries, often called photovoltaic or solar batteries incorporate several design modifications as compared to ones in their parent conventional type. The batteries are available in varying capacities and can often be designed to meet specific requirements of a particular site and system.

In india, there are about seven to eight battery manufacturers, who offer a range of PV batteries. Out of these, detailed information from five has been made available for the present study (5,18,21,34,45,46,47,48,49). These are:

1. Exide solar stationary batteries from Chloride Industries Ltd., Calcutta.
2. Tubular stationary battery from The Standard Batteries Ltd., Bombay.
3. Solar photovoltaic battery from UB-MEC Batteries Ltd., Bangalore.

4. Solar photovoltaic battery from TATA BP Solar India Private Ltd., Bangalore.
5. Sealed maintenance free battery from Amara Raja Batteries Ltd., Tirupati.

In addition, technical details of batteries from four foreign manufacturers have also been analyzed and presented in this study. These manufacturers alongwith their battery types are:

1. SUNICA Nickel Cadmium battery from SAB NIFE Inc.
2. VARTA Solar Bloc batteries from VARTA Batteries AG, Germany
3. BP Photovoltaic batteries from BP Solar, Australia
4. Stationary lead-acid tubular cells from NOACK, Sweden

Drawings and sketches, physical dimensions and other specifications of these batteries are provided in annexures A & B for ready reference and comparison. Annexure C presents their performance characteristics and addresses of the manufacturers are given in annexure D.

7.1 Range of available lead-acid batteries

7.1.1 Exide solar battery

Chloride solar of chloride India Ltd. has specially designed Exide Gauntlet tubular lead-acid batteries to provide duty cycles suitable for PV applications.

Construction

These batteries are constructed using gauntlet tubular positive plates, pasted negative plates and microporous

separators to give reliable and trouble free service. Long life and economy are expected from the design on account of using thick walled monobloc containers of good quality polypropylene or hard rubber with moulded handles for easy handling. Sealed lids have been provided with acid level indicator and ceramic flame retardant vent plugs. The vent plug is of a special type microporous inert ceramic in the shape of a dome to disallow flame entry into the cell container, thereby possibly reducing explosion hazards. The advantage of using micropores lies in reducing acid spray and venting gases generated during charging/discharging, and simultaneously preventing escape of electrolyte vapours. These vapours condense on the inner walls of plug and trickle back to the electrolyte. The terminals are made of antimonial lead provided with polythene shrounds for protection. The battery utilizes 1.220 (corrected to 27°C) battery grade sulphuric acid conforming to 1S:266 for electrolyte. The specific gravity of the electrolyte, when the battery is fully charged is adjusted to 1.240 ± 0.005 at 27°C.

'erformance characteris ics

The batteries are expected to give in excess of 10 years of service life and high cycle life:

- in excess of 1200 cycles at 80% DOD
- in excess of 2000 cycles at 50% DOD
- in excess of 5000 cycles at 10-20% DOD.

The cut-off voltage at all rates of discharge is 1.9 V per cell. The higher final discharge voltage (cut-off voltage on discharge) has been chosen specifically for PV applications in order to ensure less inter-cell voltage variation on charge/discharge, shallow cycling capability at low SOC without affecting battery life expectancy and less input voltage variation to electrical load.

Since the PV applications often are low or no sunshine operations, resulting in long rate of discharge, therefore, the capacity rating of 48 to 480 hours is provided in Exide solar batteries. The capacity appreciation ratio is also high, as per the graph in annexure B showing percentage increase in capacity with respect to 10 hr capacity with increasing duration of discharge.

Exide solar batteries offer an Ah efficiency of more than 90%, while the Wh efficiency is greater than 80%. The self discharge losses are less than 3% of C_{10} capacity per month.

nstallation and main enance

The batteries are designed to be placed on the floor over a wooden plank. The topping-up requirements of the battery are low due to the presence of ceramic vent plug. The expected topping-up frequency in tropical conditions is single in 10 to 12 months as compared to one in 4 to 6 months for designs using conventional vent plug.

Routine maintenance requirements of the battery are simple, which include avoiding possible overcharge or deep discharge, prompt recharge, distancing from flames, cigarettes and ensuring the battery temperature preferably within 50°C etc..

7.1.2 Tubular stationary battery from The Standard Batteries Limited

The Standard Batteries Ltd., has developed 6 V and 12 V monobloc batteries specially for PV applications. The capacities of some of these batteries have been worked out and developed to be equivalent to the BP Solar U.K. range of solar batteries. 2 V range is also available for PV applications.

The batteries are encased in hard rubber monobloc containers and are normally installed on wooden stillage with series and parallel connection to obtain required voltage capacity.

At 80% DOD, the batteries offer a cycle life of 1200 cycles, while the same at 50% DOD is in excess of 2500 cycles. The cycle life in excess of 6000 cycles is offered in the range of 10-20% DOD. These batteries have an efficiency of 90% with respect to C10 rate of discharge/ charge. The specified end-of-charge voltage is 1.85 V or 1.75 V. The capacity appreciation ratio is high as shown in the graph in annexure C.

7.1.3 Solar photovoltaic battery from UB-MEC Batteries Limited

Stationary low maintenance lead-acid cells have been manufactured by UB-MEC Batteries Ltd. (United Breweries Ltd., Mysore Electro Chemical Works Ltd.,) for PV applications in the range of 2 and 6 volts. The cells are made using low antimony alloy with selenium grids for both the plates to reduce corrosion, topping up frequency and self discharge considerably. The cells come in hard, rubber containers with suitable plastic rope handles. The terminals of `L´ type with M-8 size bolt hole, ceramic vent plugs and sealed float cum vent plugs are also provided. The batteries are recommended for installation on wooden or plastic planks, which are non-conducting.

The Ah and Wh efficiencies with respect to C10 discharge/charge rate are 90-95% and 80-85% respectively. Possible no. of cycles offered at 80%, 50% and 10-20% DOD, are in excess of 1400, 2200 and 5500 respectively

7.1.4 Solar photovoltaic battery from TATA BP Solar India Private Limited

A tubular lead-acid battery range developed specifically for photovoltaic systems by TATA BP Solar India Private Ltd. offers long life and high reliability due to its good cycling ability, large electrolyte reservoir and minimal maintenance. The battery has an Ah efficiency higher than 95% and Wh efficiency of more than 80%. It has a temperature co-efficient of + 0.43% per degree per C rise, minimum daily SOC of 20% and minimum monthly SOC of 30%. The self discharge of

the battery is 3% per month at 20°C and 12% per month at 40°C. The no. of cycles at 80% DOD are 1200,, at 50% DOD are 3000 and 6000 at 20% DOD.

In addition to aforesaid features, all TATA BP .Solar batteries carry a 5 year conditional warranty, when supplied alongwith a TATA BP Solar system.

7.1.5 Sealed maintenance free battery from Amara Raja Batteries Limited

Amara Raja Batteries Ltd. in collaboration with GNB Industrial Battery Company, U.S.A. has recently introduced Sealed Maintenance Free (SMF) Lead-acid battery suitable for PV applications. These batteries come in two makes, namely Power Plus and Power Stack. Configurations of 12 V, 6 V and 4 V in the capacity range of 35 AH to 250 AH at C10 rate are available in Power Plus range. Physical design features of these batteries incorporate polypropylene container, pressure regulating explosion proof safety vents, separators made of spun glass microporous matrix and heavy duty copper interconnects for terminals.

These SMF batteries have absorbed electrolyte and hence are safe against acid spillage. No external gassing takes place due to oxygen recombination. The special hybrid alloy offers deep cycle capability. The self discharge rate of these batteries is 0.5% per week.

7.1.6 VARATA bloc solar batteries

VARTA Batteries AG, Hagen, Germany has a range of batteries suited for PV applications. The range offers fully

insulated bloc batteries in translucent plastic containers in 6 V units with a capacity of 12.5-150 Ah, and in 4 V units with a capacity of 175 and 200 Ah and fully insulated single cells in the capacity range of (250-2000) Ah. Due to the use of VARTA patented lead alloy, the water consumption is minimized. The electrolyte reserve lasts for about 3 years in PV applications. These can be stored for unlimited duration in a 'dry charged' condition. The basic battery design includes square electrodes, hanging positive plates, safety pole construction and recombinator vent plugs. These vent plugs can offer a lifelong maintenance free operation.

The batteries possess the mechanical strength to withstand vibration and shocks during earthquakes. It is possible to fit these batteries into all types of containers, slide-in units, rooms and bunkers; provided, the ventilation requirements are satisfied.

7.1.7 BP photovoltaic batteries

The BP Solar Australia Private Ltd., offered the first commercially available range of batteries developed specifically for PV use. The range called P-series was introduced in 1979 and has a comprehensive product range from 207 to 1101 Ah capacity at 100 h rate. In typical PV applications, the P-series battery cell gives a minimum life-expectancy of 8-10 years. BP solar batteries carry a five year product guarantee.

7.1.8 NOACK stationary tubular cells

NOACK stationary lead-acid tubular cells, though not specifically designed for PV installations, are still suitable for PV applications on account of their attractive design and performance features.

Summary and comparison of physical and performance features of all the above mentioned batteries are presented in exhibit 7.1.

7.2 SUNICA NiCd battery from SAB NIFE Inc.

The SUNICA battery claims to surpass the performance of lead-acid batteries in PV applications as it offers:

* high Ah efficiency
* low self discharge
* no risk of sudden death
* no need for a voltage regulator
* no need for a battery oversizing
* works at any SOC
* works in arctic cold and in tropical heat
* withstands temperature extremes

The battery comes in a translucent polypropylene container with a hard PVC plastic dead top. The active material (nickel hydroxide on positive plate and cadmium oxide on negative plate) in the SUNICA battery is enclosed in pockets of nickel-perforated steel strips. The amount of active material in the plates is balanced to match the charge/ discharge characteristic for PV applications.

Current collectors and mechanical connections are all made of steel, hence, no sudden death of the battery due to corrosion occurs. It has a large volume of free electrolyte with a surplus one. Spill-proof flame arresting vent made of polypropylene and teflon keep the electrolyte losses to a minimum.

Since the battery is not destroyed either due to over or undercharging, a voltage regulator is not needed. However, it might be required to meet the demands of connected load.

Exhibit 7.2 presents performance features of SUNICA battery.

7.3 Comments and general observations on lead-acid PV batteries

7.3.1 Physical design and other details

As per the exhibit 7.1, most of the solar or photovoltaic batteries incorporate tubular positive and pasted negative plates made of lead alloy with low antimony content. Exide solar range has gauntlet tubular positive plate design, in which positive active material of each plate is encased in a one-piece multi-tube woven gauntlet of high tensile acid-resistant terylene. The fine weave of the fabric retains the active material in place, while allowing free access of electrolyte to an instant and unimpeded reaction. The gauntlet design is capable of withstanding the stresses of contraction and expansion of the active material during charge and discharge.

Exhibit 7.1: Technical specifications and other features of commercially available PV Lead-acid batteries

Specifications and other features	Exide solar from Chloride Industries Limited	Tubular stationary battery from The Standard Batteries Limited	Solar Photovoltaic batteries from UB-MEC Batteries Limited	Solar photovoltaic batteries from TATA BP Solar India Private Limited
Construction	Gauntlet tubular positive plate pasted negative plate		Low antimony alloy with selenium grids for tubular positive plate and pasted negative plate	
	Microporous separators		Microporous PVC separator	
	Hard rubber thick walled monobloc container with moulded handles	Hard rubber monobloc containers	Hard rubber container with suitable rope handle	Hard rubber or poly propylene container
	Microporous inert ceramic in the shape of dome for vent plugs Sealed lids with acid level indicating floats		Vent plugs either ceramic or Aquagen type to recombine H_2 and O_2 into water, which falls back in the cell	Vent plug either with flame arrestors or a catalytic vent plug recombinator system.
	Terminals made of antimonial lead, provided with polythene shroud		Sealed float cum vent plug 'L' type terminal with M-8 size bolt hold	
Typical battery type	6 TSV 115 H 6 V, 115 Ah at 27°C when discharged at 10 hr rate to 1.9 V per cell	3 SPG 4 B/LM 6 V, 120 AH at 27°C when discharged at 10 hr rate to 1.85 V per cell	3 MQ 120 HLM 6 V, 120 AH at 27°C when discharged at 10 hr rate to 1.85 V per cell	Solar 6-180 6 V, 120 AH at 27°C when discharged at 10 hr rate to 1.80 V per cell
Physical dimensions	L 315 ± 3 mm W 181 ± 3 mm H 400 ± 3 mm	383 ± 5 mm 187 ± 5 mm 380 ± 5 mm	350 ± 3 mm 170 ± 3 mm 377 ± 3 mm	440 mm 176 mm 385 mm
Weight	Wet 34.5 kg Dry 23.5 kg	43 kg 32 kg	39 kg (approx.) 29 kg (approx.)	51 kg 36 kg

Electrolyte volume	8.7 litres	9.0 litres	8.5 litres	
Cycle life at 80% DOD at 50% DOD at 20% DOD	> 1200 cycles > 2000 cycles > 5000 cycles	1200 cycles > 2500 cycles > 6000 cycles	> 1400 cycles > 2200 cycles > 5500 cycles	1200 cycles 3000 cycles 6000 cycles
Ah efficiency Wh efficiency	> 90% > 80%	> 90%	90-95% 80-85%	95% 80%
Self discharge losses	> 3% of C_{10} capacity per month			3% per month at 20°C 12% per month at 40°C
Specified end-voltage	1.9 V per cell	1.75 or 1.85 V per cell	1.8 V per cell	1.8 V per cell
Filling sp.gr. of electrolyte	1.220 at 27°C	1.230 ± 0.005 at 27°C	1.200 ± 0.005 at 27°C	
Final sp.gr. of electrolyte	1.240 ± 0.005 at 27°C	1.250 ± .005 at 27°C	1.225-1.235 at 27°C	
Charging: Current starting	not less than 0.1 I_{120}		15% of C_{10} capacity upto 2.4 V per cell	
finishing	Not more than finishing rate after 2.25 V per cell		7.5% of C_{10} capacity up to full charge	
temperature	48-54°C			
Topping-up requirement	Once in 10-12 months		Once in 9-12 months	Once in 12 months
Temperature coefficient	0.007% per °C rise			0.43% per °C rise
Other remarks				5 year conditional warranty

...ecifications and ...ther features	SMF batteries from AMAR RAJA Batteries Ltd.	VARTA solar bloc batteries	BP Photovoltaic batteries	HOACK stationary tubular cell .
...onstruction	Patented MFX alloy for positive plate, lead calcium alloy for negative plate Spun glass, microporous matrix separator Polypropylene container Pressure regulating, explosion proof vent plugs Heavy duty copper inserts for terminals Oxygen recombinator Absorbed electrolyte and sealed construction	Patented special alloy 1.6 pct Sb for grids giving high energy throughout and high cycling capability Translucent plastic containers with insulated copper connectors, safety poles and pole-caps Recombinator type vent plugs making these batteries maintenance free during the life span of the battery	Large electrolyte reservoir contained within tough transparent SAN casing Flame arrestors	Low antimony (1.6 pct) alloy for tubular positive plates, pasted grids negative plate Transparent SAN plastic containers with level marks Protective connector covers and flame-arresting vent plugs.
...pical battery ...pe	6165 6 V, 165 AH at 25°C when charged at 10 hr rate to 1.75 V per cell	VB 625 6 V, 125 Ah at 20°C when discharged 10 h rate to 1.85 V per cell	6 P 207 6 V, 95 Ah at 25°C when discharged at 10 h rate to 1.8 V per cell	6 SR 21 ELSG 300 Ah at 20°C when discharged at 10 h rate to 1.83 V per cell
...ysical dimensions	L 305 mm W 173 mm H 216 mm	283 mm 229 mm 332 mm	272 mm 205 mm 379 mm	151 mm 212 mm 426 mm
...ight	Wet 28 kg Dry	39.72 kg 29.29 kg	37.5 kg 23.8 kg	25 kg 18 kg
...id density for ...lly charged cells ...t 20°C		1.24 kg/l		1.24 kg/l
...ycle life/cyclic ...bility/life ...pectancy	Deep cycle capability	1300 cycles at 75% DOD > 10 years of life	7200 cycles to 10% DOD (20 years life estimated) 3000 cycles to 50% DOD (8 years life estimated) 1600 cycles to 75% DOD (4 years life estimated)	
...efficiency		95-98%	97% (upto 60% SOC)	
...efficiency		85%		

Self discharge losses	0.5% per week	3% per month	2.3% per month	
Specified end voltag	1.75 V per cell	1.85 V per cell	1.8 V per cell	1.9-1.7 V per cell
Charging	Current limited constant potential charging	Can be fully charged with 0.001 I_{10} rated current, recommended voltage to be 2.35 V per cell		Normal float charging voltage 2.23 ± 0.01 cell charging volta- not to exceed 2.4 V/ cell charging current not higher than 0.05 I_{10} during gassing Highest allowed char ing voltage is 2.7 V/ cell
Topping-up requirement	Nil			
Other remarks			5 year product guarantee	

Exhibit 7.2: Technical specifications and other features of SUNICA NiCd battery

Features	
Typical battery type	SUN 10-5, 6 V, 110 Ah at 100 h rate
Dimensions	L 252 mm W 195 mm H 349 mm
Weight	total 28 kg
Electrolyte reserve	0.5 l/cell
Ah efficiency	> 95%
Self discharge losses	0.1-0.2% per day at 25°C
Acceptable DOD	100% in both daily and seasonal cycles
Capacity appreciation ratio	1.08 (C_{100}/C_5) 1.03 (C_{10}/C_5)
Cycle life as a fn. of DOD	1200 cycles by 95% of rated capacity at 10% daily DOD 1200 cycles by 88% of rated capacity at 20% daily DOD 1200 cycles by 83% of rated capacity at 40% daily DOD

High temperature effect on battery life

Continual operating T (°C)	% life cut
25	0
35	20
45	35
55	47

Microporous separators, heavy duty terminals and low resistance bolted connections, ceramic vent plugs fitted with acid level indicators, flame arrestors and oxygen-hydrogen recombination systems form common physical features of all the available batteries. Also translucent hard rubber or polypropylene monobloc containers with a large reservoir capacity are usually used. BP solar and NOACK batteries come in transparent SAN casing.

Specially designed photovoltaic batteries are available in 2 V, 6 V and 12 V range with varying Ah capacity as offered by most of the manufacturers. Series and parallel connections of available monobloc cells can be used for higher voltage current requirements.

A range of typical battery type (6 V, 100-120 Ah) listed in exhibit 7.1, vary in physical dimensions and weight from one manufacturer to the other one. The weight of electrolyte is in the range of 10-11 kg except in respect of batteries available from TATA BP Solar India and BP Solar, Australia, or with common electrolyte weights of about 15 kg.

7.3.2 Performance

State-of-the-art photovoltaic batteries offer Ah and Wh efficiencies of more than 90% and 80% respectively and low self-discharge losses. For typical PV applications (approximately 50% DOD), TATA BP Solar India batteries offer maximum number of cycles and a life expectancy of 8-10 years.

The specified cut-off voltage is highest for the Exide make of batteries available from Chloride Industries. Choice of a higher final discharge voltage or cut-off voltage at any rate of discharge for PV applications ensures minimum inter-cell voltage variation on discharge/charge in a battery bank, shallow cycling capability at low SOC without affecting battery life expectancy severely and lesser input voltage variation to the electronic/electrical loads.

The normal charging of PV batteries is done at current limited constant potential. The charging currents, both at the start and end are specified for each battery type by its manufacturer. Charging curves for UB-MEC solar PV battery and for TATA BP solar batteries are given in annexure 3.

The temperature coefficient, which indicates the effect of electrolyte temperature on its specific gravity and hence the capacity of the battery, is 0.007% per 1°C rise for Exide solar battery. The value of this coefficient for TATA BP solar batteries is 6 times higher than that for Exide solar. Conventionally for lead-acid battery, the coefficient is about 1% per 1°C. The temperature coefficient of Exide solar battery appears insignificant when compared to above value.

For PV applications, a capacity rating of 2 to 20 days is important as the no-sun operation leads to longer rate of discharge. Each manufacturer routinely supplies curves of percentage increase in capacity relative to 10 h capacity with increasing duration of discharge. These curves, enable

a PV designer to obtain the capacity at any discharge rate. The capacity appreciation ratio calculated from the data supplied by various manufacturers is given below:

Capacity appreciation ratio

Exide solar batteries	1.44	(C_{120}/C_{10})
The Standard batteries	1.40	(C_{120}/C_{10})
UB-MEC batteries	1.48	(C_{120}/C_{10})
TATA BP solar batteries	1.50	(C_{120}/C_{10})
Amara power plus batteries	1.84	(C_{10}/C_{1})
VARTA Bloc solar battery	1.50	(C_{120}/C_{10})
BP solar batteries	2.18	(C_{100}/C_{10})
NOACK stationary battery	2.2	(C_{10}/C_{1})

The capacity appreciation ratio is between 1.4-1.5 for most of the batteries at 120 h rate with respect to 10 h rate. A higher capacity appreciation ratio is desirable, as it reduces the battery size and hence the cost.

From the family of discharge curves given for each battery type by its manufacturers, the battery voltage at the end of 10 h at C_{10} rate for various battery types have been obtained, which are given below:

Battery type	Battery voltage		Discharge rate
	Beginning	At the end of 10 h	
Exide solar	2.01 V	1.95 V	C_{10}*
Standard batteries	2.0 V	1.88 V	C_{10}
UB-MEC batteries	2.04 V	1.86 V	C_{10}
TATA BP solar batteries	2.01 V	1.9 V	C_{10}
VARTA Bloc solar batteries	2.03 V	1.85 V	C_{10}

7.3.3 Specific energies

From the specifications given by various manufacturers on different battery types, specific energies with respect to weight and volume were calculated at 10 hr rate. While values for all chosen battery types including SUNICA NiCd fall within a range of 13-20 Wh/kg and 21- 33 x 10^3 Wh/m^3, those for AMAR power plus SMF LA battery are exceptionally high, almost by factors of 2 and 3 respectively. Specific energies for AMAR power plus 12 V, 35 Ah battery are 30 Wh/kg and 74.4 x 10^3 Wh/m^3 (exhibit 7.3). The manufacturers claim of introducing a 30% lighter and compact battery (18) appears modest when compared on the basis of these values.

Correspondingly, the weight-to-volume ratio is high (2.48 x 10 ^{3} kg/m^3) for SMF LA battery as compared to rest of the available ones; having these ratio in the range of 1.47 - 1.87 x 10^3 kg/m^3.

7.3.4 Installation and maintenance

Normally recommended installation procedure for most of these batteries relates to their placement either on floor or on wooden planks in a separate room with adequate ventilation. Acid proof steel stands and steel cubicles may also be used for housing VARTA bloc solar batteries, provided cubicles satisfy the ventilation requirements.

Topping-up requirements except for AMAR power plus range of batteries vary once in 10 to 12 months; it is nil for AMAR power plus battery on account of its maintenance-free sealed design, since they can be installed in any position.

7.4 A comparison between NiCd and SMF LA batteries: SUNICA & AMAR Power Plus

Exhibit 7.4 compares various design and performance features of SUNICA and AMAR Power Plus batteries.

The comparison shows that SMF lead-acid battery has a potential for competing well with the NiCd battery. In fact, some of features indicate that SMF LA has a favourable edge over NiCd for PV applications. The costs, which are not available for this study would play significant roles in deciding their future as acceptable options.

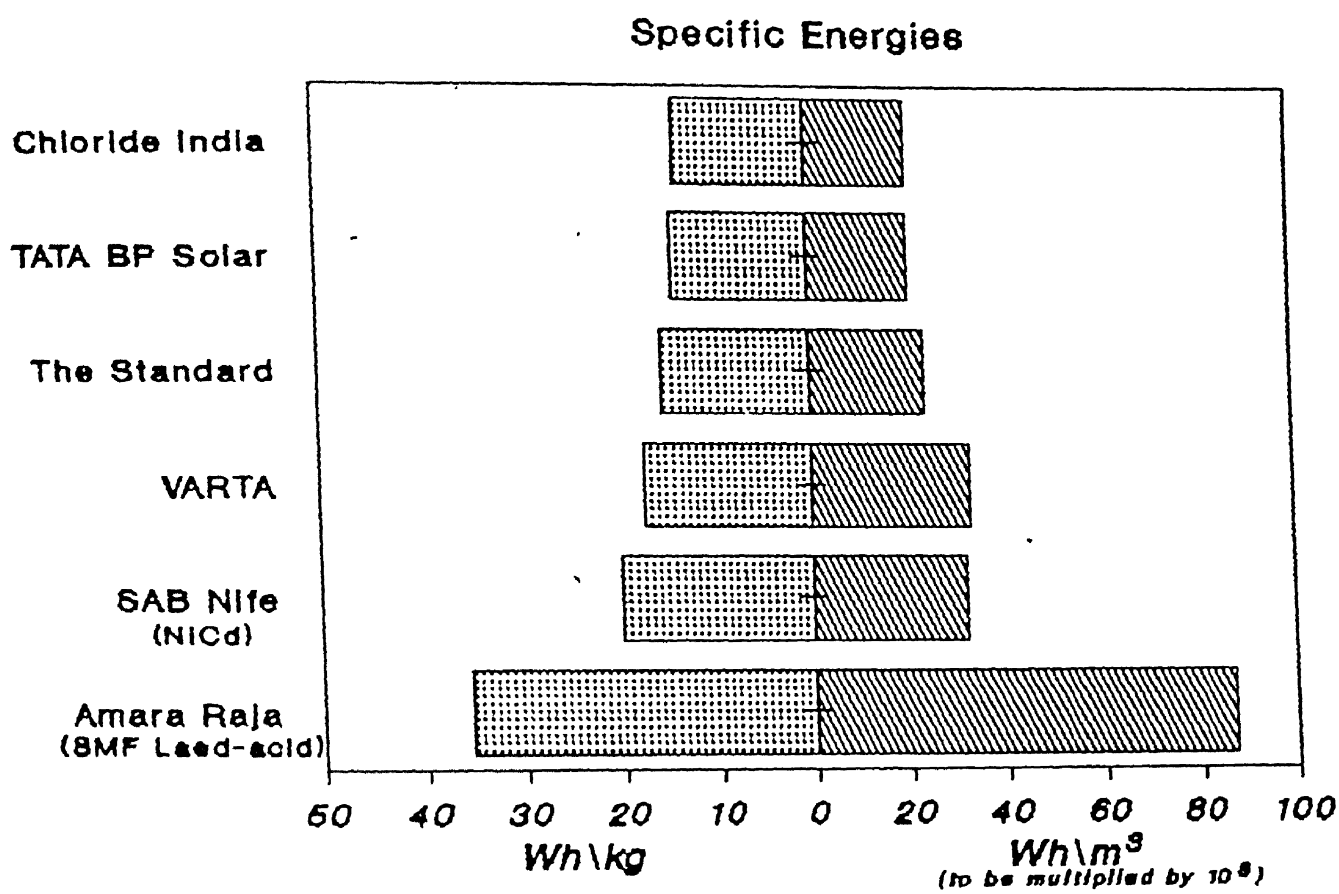

Specific Energies
Chloride India
TATA BP Solar
The Standard
VARTA
SAB Nife
(NiCd)
Amara Raja
(SMF Lead-acid)
60
40
30
20
10
0
20
40
60
80
100
Wh\kg
Wh\m3
(to be multiplied by 10 3)

Exhibit 7.3

Exhibit 7.4: Comparison of SUNICA NiCd and AMAR Power Plus SMF LA batteries

SUNICA NiCd	AMAR Power Plus SMF LA.
* Translucent polypropylene container used for both are non-aging and shockproof.	
* Minimum electrolyte losses achieved with the help of spill-proof vent made of polypropylene or teflon	Oxygen recombination system with no external gassing. Self releasing safety plugs provided.
* Plate group bus connects the plate tabs with the terminal ports, both of which are spot-welded to plate group bus.	Heavy duty lead plated copper connectors, with 316 stainless steel bolts and washers used.
* 10 years of maintenance-free service after which topping-up with water needed.	Life long maintenance-free service
* More than 80% capacity available after 1300 cycles of 40% daily DOD	3% decrease in electrolyte after 1500 cycles of 80% DOD
* Capacity appreciation ratio 1.03 (C_{10}/C_5)	Capacity appreciation ratio 1.17 (C_{10}/C_5)
* Ah efficiency 95%	Ah efficiency 95-98%
* Self discharge 0.1-.02% per day at 25°C	Self discharge 0.5 to 1% capacity per week
* 100% DOD and deep cycle capability common to both	
* Unaffected by low temperatures	
* Specific energies for 6V 70 Ah battery at 10 h rate:	Specific energies for 12 V, 35 Ah battery at 10 h rate
20 Wh/kg, 32 x 10^3 Wh/m^3	30 Wh/kg, 74 x 10^3 Wh/m^3
* 20 years of service life	20 years life expectancy under float service

8.0 Lead-acid Battery Industry

At present in India, the lead-acid battery manufacturing units are found in small, medium and the large scale sectors. Battery assemblers, reconditioners, small plate manufacturers belong to small and medium scale sectors. Facilities for manufacturing all the components, their assembly and battery testing, currently exist within large sector. As per an estimate (50), there are 15 such large sector units whereas, nearly 200 small scale manufacturers of lead-acid batteries are spread all over the country. About 3500 assemblers and reconditioners, and 200 battery components manufacturers specializing in containers, separators and lead oxide also exist.

Starting with a modest figure of 90,000 batteries in 1947, it rose to 2,51,564 in 1950 with automotive and industrial batteries numbering 40,00,000 and 7,00,000 in 1989 respectively. These figures are indicative of the progressive growth of industry during last four decades. Currently, almost all large scale manufacturers are manufacturing stationary battery for different applications including those meant for solar and wind power generation (50).

A number of small scale battery manufacturers, spread countrywide which collectively account for a large production volume, use crude manufacturing methods without any care for quality control. Whereas, the battery industry worldwide including large scale sector battery manufacturing units in

India, have introduced several automatic processes which are directed at reducing both labour and overhead costs. Battery manufacturer's worldwide are now using polypropylene, heat-sealed containers and lids with through-the-partition extrusion fusion intercell connections (51). Also, majority of them use either grain-refined, very low antimonial or lead-calcium alloys for grid-production. Such batteries are named `maintenance-free' batteries which also offer better manufacturing designs like cell-through partition to reduce the inactive lead weight of the battery, valve-type acid-arresting vent plugs etc. (52).

Battery grids which now incorporate computer-aided designs (52), are mainly produced using grid casting machine throughout the world. These machines now have automated control systems. Continuous casting, an alternative approach for manufacturing grids appears to be a major contender for a large-sized factory. For oxide production, ball mill and Barton pot remain the two manufacturing routes (51). In India, ball-mill route is the most commonly used one (50).

The method of preparing pastes remains the batch process, with improvements having been made in the paste preparation. Pasting of low antimony or lead-calcium alloy grids is done universally using latest designs of belt pasting machines, which are complete with horizontal drying oven and shingle type take off conveyor. Pre-cutting of grids before pasting, a recent trend adopted by the industry,

eliminates plate cutting of unformed plates, thus reducing the amount of high-value scrap associated with the process.

For the curing or the plate setting, special ovens having preset humidity and temperature profiles are being incorporated into the modern battery factories. Regarding the process techniques employed for dry-charged or jar-formed (wet-charged) products, particularly plates, developments have been made especially with a view to reduce work-in-progress (WIP). It is now possible to have a 24 h formation schedule for car batteries through the introduction of stepped programmes, temperature sensing and customized charging bays complete with forced drought cooling arrangements in jar-formation process.

An outcome of introducing all these automated and modern techniques during manufacturing process is evident from the improved throughput figures achieved by the industry. Modern assembly lines producing automotive batteries of upto 80 Ah have throughputs between 600-800 per eight hour shift (51).

The future developments especially in medium scale factory are expected to be in the area of control systems for monitoring and controlling processes, raw material inputs and for assisting in breakdown prediction and maintenance planning. Expanded or continuous cast-grids, followed immediately by plate cutting, pasting and sharp drying, techniques as per the study (51), would only be employed by a

few large scale manufacturers. Since the lead-acid PV battery manufacture is an activity confined mostly to large scale units, the automation is likely to improve the performance reliability and favour overall cost reduction.

9.0 Battery Terminology

Definitions of terminology common to batteries are presented in alphabetical order in this section.

Activation polarization: The polarization resulting from the rate-determining step of the electrode reaction.

Active material: The constituents of a cell that participate in the electro-chemical charge-discharge reaction.

Anode: The electrode in an electrochemical cell at which chemical oxidation takes place. During charge, the positive terminal of the cell is the anode. During discharge, the situation reverses and the negative terminal of the cell is the anode. However, battery manufacturers sometimes refer to the negative terminal as the anode during both charge and discharge.

Anolyte: The electrolyte associated with the anode in an electrochemical cell. In a secondary battery, the anolyte is associated with the negative terminal.

Battery: Two or more electrochemical cells electrically interconnected in an appropriate series or parallel arrangement to provide the required operating voltage and current levels. Under common usage, the term battery also applies to a single cell if it constitutes the entire electrochemical storage system.

Capacity C: Generally, the total number of ampere-hours that can be withdrawn from a fully charged cell or battery.

Capacity, available: The total number of ampere-hours that can be withdrawn from a cell or battery for a specific set of operating conditions including discharge rate, temperature, initial state of charge, age and cut-off voltage.

Capacity, energy: The total number of watt hours (kilowatt hours) that can be withdrawn from a fully charged cell or battery. The energy capacity of a given cell varies with temperature, rate, age and cut-off voltage. This term is more common to system designers than it is to the battery industry where the capacity usually refers to ampere hours.

Capacity, installed: The total number of ampere hours that can be withdrawn from a new cell or battery when discharged to the system specified cut-off voltage at the system design rate and temperature (i.e. discharge to the system design specified maximum depth of discharge).

Capacity, rated: The manufacturer's conservative estimate of the total number of ampere hours that can be withdrawn from a new cell or battery for a specified discharge rate, temperature and cut-off voltage.

Cathode: The electrode in an electrochemical cell at which chemical reduction takes place. During charge, the negative terminal of the cell is the cathode. During discharge, the situation reverses and the positive terminal of the cell is the cathode. However, battery manufacturers sometimes refer to the positive terminal as the cathode during both discharge and charge.

Catholyte: The electrolyte associated with the cathode of an electrochemical cell in a secondary battery. The catholyte is usually associated with the positive terminal.

Cell: The basic electrochemical unit used to store electrical energy.

Charge rate: The current applied to a cell or battery to restore its available capacity. This rate is commonly normalized with respect to the rated capacity of the cell or battery. For example, the 10 h charge rate of a 500 Ah cell or battery is expressed as:

$$\frac{\text{rated capacity}}{\text{charge time}} = \frac{500\ \text{Ah}}{10\ \text{h}} = 50\ \text{A} = \frac{C}{10}\ \text{rate or}\ C_{10}$$

For the same cell or battery, a 5 h charge rate would be designated the C/5 rate and would result in a charging current of 100 A. Unfortunately, the ampere hour efficiency of many secondary batteries is less than 100%. Therefore, the time required to recharge one cell completely, from 100% depth of discharge, is often longer than indicated by the so-called `hour rate´.

Charging: The conversion of electrical energy into chemical potential energy within a cell by the passage of a direct current in the direction opposite to that of discharge.

Coefficient of use: The percentage of total active material contained within a cell that is converted during the discharge of 100% of rated capacity. (Also called utilization factor).

Concentration polarization: Polarization caused by the depletion of ions in the electrolyte at the surface of the electrode.

Cut-off voltage: The cell or battery voltage at which discharge is terminated. The cut-off voltage is specified by the cell manufacturer and is generally a function of discharge rate. Discharge beyond the specified cut-off voltage usually results in increasingly rapid decreases in cell voltage and energy output, it may permanently damage the cell and it may void a manufacturer's warranty. (Also called final voltage).

Cycle: One discharge-charge sequence to a specified depth of discharge.

Cycle life: The number of cycles, to a specified depth of discharge, that a cell or battery can undergo before failing to meet its specified capacity or efficiency performance criteria.

Cycle service: A duty cycle characterized by frequent and usually deep discharge-charge sequences, such as motive power applications.

Deep discharge: The withdrawal of a significant percentage of rated capacity (50% or more).

Depth of discharge (DOD): The ampere hours removed from a fully charged cell or battery, expressed as a percentage of rated capacity. For example, the removal of 25 Ah from a

fully charged 100 Ah rated cell results in a 25% depth of discharge. Under certain conditions, such as discharge rates lower than that used to rate the cell, the depth of discharge can exceed 100%.

Discharge: The process of withdrawing current from a cell or battery by the conversion of chemical energy into electrical energy.

Discharge rate: The current removed from a cell or battery. This rate can be expressed in amperes, but more commonly, it is normalized to rated capacity C and is expressed as C/X. For example, drawing 20 A from a cell with a rated capacity of 100 Ah is referred to as the C/5 discharge rate (100 Ah/20 A). Similarly, discharge currents of 5 A, 10 A and 33.3 A would be designated as the C/20, C/10 and C/3 rates respectively.

Efficiency: The ratio of the useful output to the input.

Efficiency, ampere hour (Coulombic): The ratio of the ampere hours removed from a cell or battery during a discharge to the ampere hours required to restore the initial capacity:

$$\frac{\text{Ampere hours discharged}}{\text{Ampere hours of charge}} = \frac{\int_{o}^{t_d} i_d \, dt}{\int_{o}^{t_c} i_c \, dt}$$

where i_d and i_c are the discharging and charging currents respectively, and t_d and t_c are the discharging and charging times respectively.

Efficiency, voltage: The ratio of the average discharge voltage of a cell or battery to the average charge voltage during the subsequent restoration of an equivalent capacity.

Efficiency, energy (watt hour): The ratio of the energy delivered by a cell or battery during a discharge to the total energy required to restore the initial state of charge. The watt hour efficiency is approximately equal to the product of the voltage and ampere hour efficiencies. This is sometimes referred to as the round-trip efficiency. round-trip energy efficiencies usually do not include energy losses resulting from self-discharge, auxiliary equipment (parasitic losses) or battery equalization.

Electrochemical couple: The system of active materials within a cell that provides electrical energy storage through an electrochemical reaction.

Electrolyte: The medium which provides the ion transport mechanism between the positive and negative electrodes of a cell. In some cells, such as the lead-acid type, the electrolyte may also participate directly in electrochemical charge-discharge reactions.

End-of-charge voltage: The cell or battery voltage at which the finishing charge is normally terminated by the charging source.

Energy density: The ratio of rated energy available from a cell or battery, normalized to its weight or volume.

Equalization: The process of restoring all cells in a battery to an equal state of charge. For lead-acid batteries this is a charging process designed to bring all cells to 100% state of charge. Some battery types may require a complete discharge as a part of the equalization process.

Equalizing charge: A continuation of normal battery charging, at a voltage level slightly higher than the normal end-of-charge voltage, in order to provide cell equalization within a battery.

Finishing charge rate: The rate specified for charging a cell or battery that is nearing 100% state of charge.

Float service: A duty cycle characterized by long periods of standby operation, at full charge and constant voltage, with only occasional discharge-charge sequences.

Formation: The process, during manufacture or installation, by which the electrode materials are transformed into the compositions required for cell operation. For example, the active materials of a fully charged lead-acid cell are pure lead for the negative and lead dioxide for the positive plates. However, both plates are manufactured using lead oxide. During a specially designed charging cycle, the lead oxide on the negative plates is reduced and the lead oxide on the positive plates is oxidized, thereby forming the active materials.

Gassing: The evolution of gas from one or more of the electrodes in a cell. Gassing commonly results from local action (self-discharge) or from the electrolysis of water in the electrolyte during charging.

Grid: An electrically conductive structure that supports the active material of a plate but does not chemically participate in the normal charge-discharge reaction.

Hour rate: The discharge rate of a cell or battery expressed in terms of the length of time that a new fully charged cell or battery can be discharged at a specific current before reaching a specified cut-off voltage.

Hour rate = C/i

where C is the rated capacity of the cell or battery and i is the specified discharge current. For example, if a new, fully charged cell rated at 100 Ah can be discharged at 20 A for a period of 5 h before reaching the cut-off voltage, discharge of the battery at 20 A is referred to as the 5 h rate (C/i = 100 Ah/20 A). Unfortunately, for most cells, the available capacity is not constant with discharge rate. Therefore, the discharge current cannot always be calculated by dividing discharge time into rated capacity. For example, a lead-acid battery with a rated capacity of 100 Ah at the 5 h rate may only deliver 88 Ah at the 3 h rate before reaching the cut-off voltage. The discharge current at the 3 h rate would therefore be 29.3 A rather than 33 A as might otherwise be expected and would be designed as the C/3.4 rate.

Hours of capacity: The total number of hours for which fully charged cell or battery is capable of supplying the system load demand before reaching the specified maximum depth of discharge.

Life: The period during which a cell or battery is capable of operating above a specified capacity or efficiency performance level. For example, with lead-acid batteries, the end of life is generally taken as the point in time when a fully charged cell can only deliver 80% of its rated capacity. Beyond this state of aging, deterioration and loss of capacity begins to accelerate rapidly. Life may be measured in cycles and/or years, depending on the type of service for which the cell or battery is intended.

Local action: The chemical reactions within a cell that convert the active materials to a discharged state without supplying useful energy through the battery terminals (self-discharge).

Motive power cell or battery: A cell or battery that is intended to power electrically operated mobile equipment (fork-lift trucks) and is designed to be operated in a daily deep-cycle regime at moderate (C/6) discharge rates.

Nominal operating voltage: The average terminal voltage of a cell or battery discharging at a specified rate and at a specified temperature.

Open-circuit voltage: The terminal voltage of a cell or battery at a specified state of charge and temperature under no-load conditions.

Overcharge: The forcing of current through a cell after all the active material has been converted to the charged state. In other words, charging continued after 100% state of charge is achieved. Overcharging does not increase the energy stored in a cell and usually results in gassing and/or excessive heat generation, both of which reduce battery life.

Plate: An assembly of active material and, in some cases, a support grid. The plates form the positive and negative electrodes of the cell.

Polarization: The deviation from open-circuit voltage caused by the flow of current in an electrochemical cell.

Power density: The ratio of the rated power available from a cell or battery, normalized to its weight or volume.

Primary cell or battery: A cell or battery whose initial capacity cannot be significantly restored by charging and is therefore limited to a single discharge.

Reversal: The continued discharge of a cell to the point that the cell's electrical terminals change polarity.

Reversible potential: The open-circuit (zero-current) potential of a reversible chemical reaction.

Secondary cell or battery: A cell or battery that is capable of being charged repeatedly.

Self-discharge: The process by which the available capacity of a cell is reduced by internal chemical reactions (local action).

Self-discharge rate: The amount of capacity reduction occurring per unit of time in a cell as the result of self-discharge.

Separator: An electrically non-conductive and ionic permeable material used to prevent the direct contact of individual plates within a cell.

Starting, lighting and ignition (SLI battery): A battery (standard automotive battery) designed primarily for high rate, low depth-of-discharge operation typical of automobile engine starting.

Stationary cell or battery: A cell or battery that is generally intended for float-service usually in a fixed location.

State of charge (SOC): The available capacity in a cell or battery expressed as a percentage of rated capacity. For example, if 25 Ah have been removed from a fully charged 100 Ah cell, the new state of charge is 75%.

Sulphation: The formation of lead sulphate crystals on the plates of a lead-acid battery. Commonly used to indicate the

large crystals which form in partially discharged cells as the result of temperature cycling. These large crystals are more difficult to reduce by the charging current than are the smaller crystals that result from normal and self-discharge reactions. sulphation can be caused by leaving the battery in a discharged state for long periods of time.

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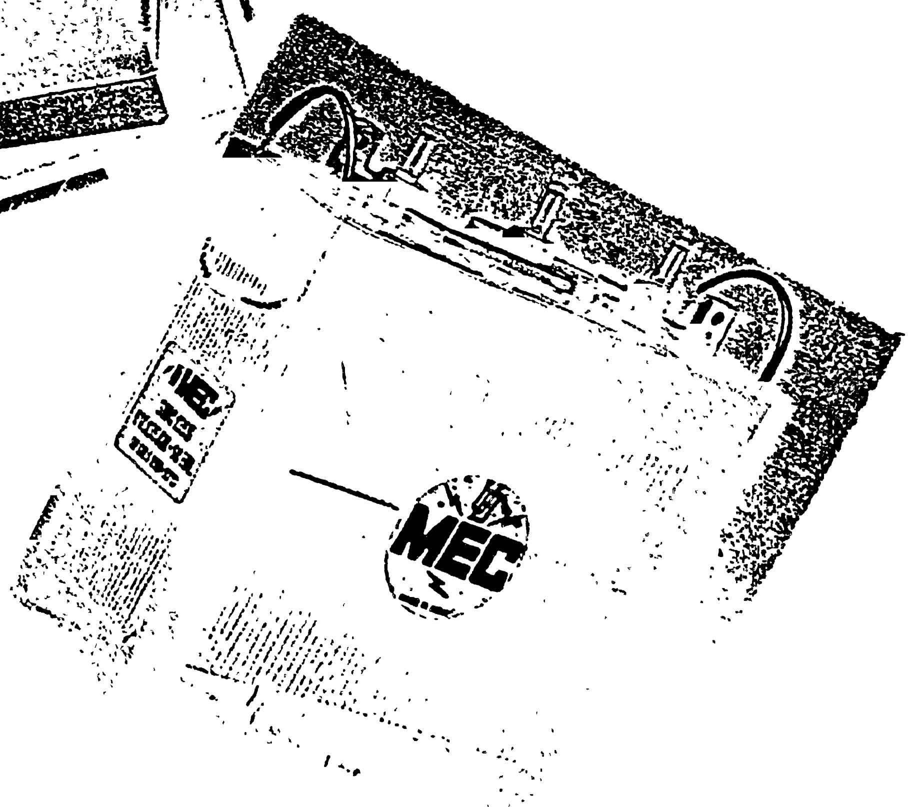
Annexures

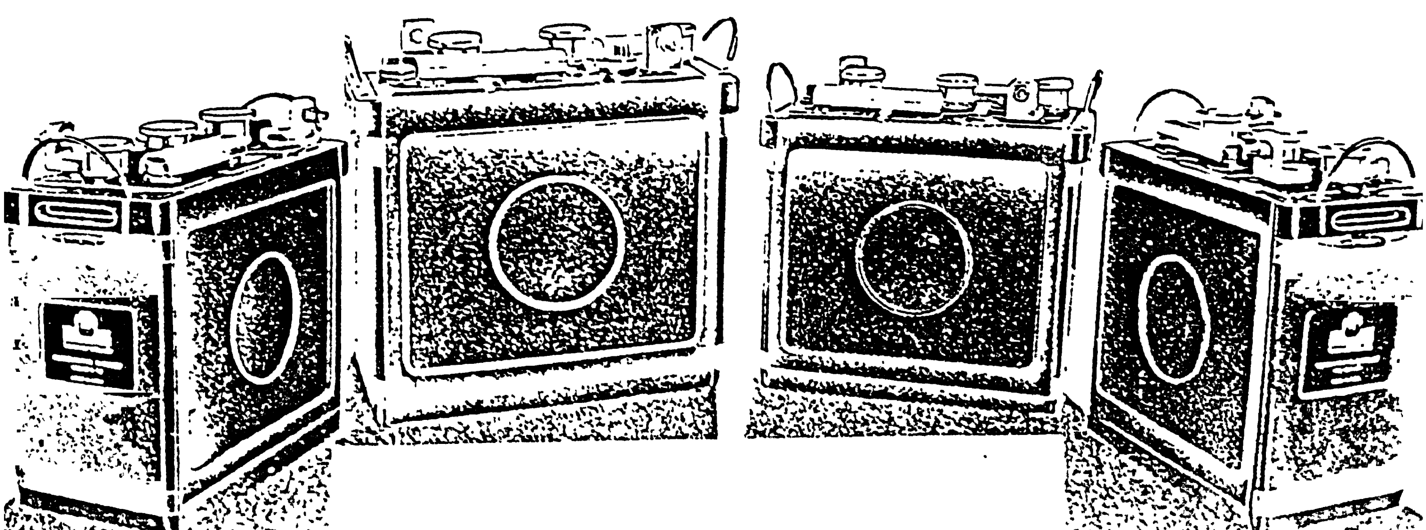
A1-A3: Commercially available PV batteries

B1-B5: Technical specifications of available battery range

C1-C6: Performance characteristics of available batteries

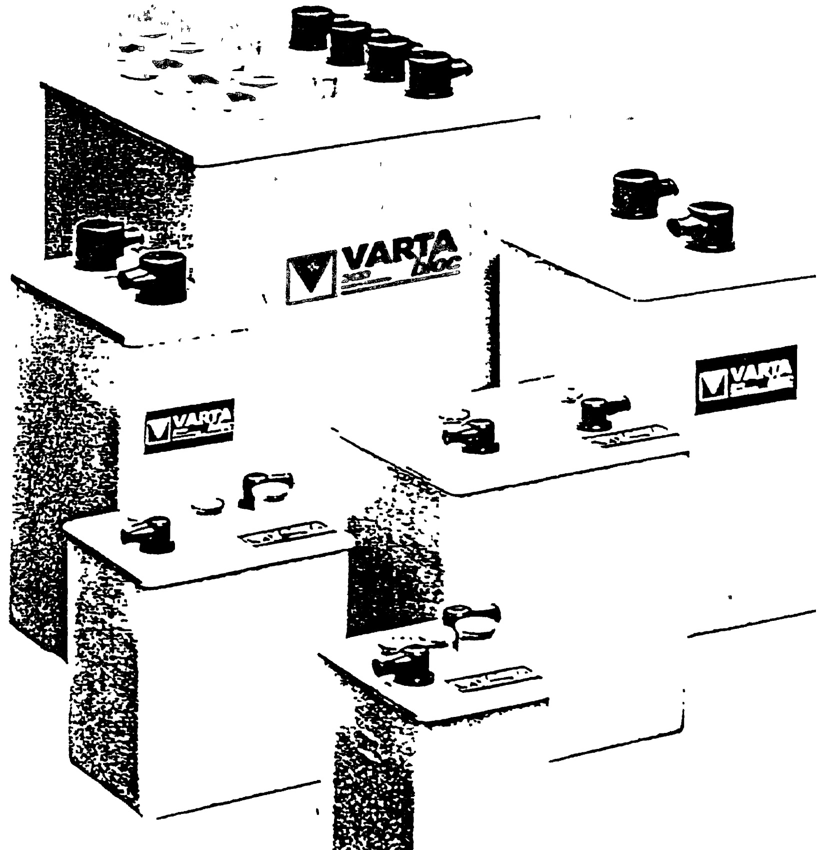
D : Addresses of battery manufacturers

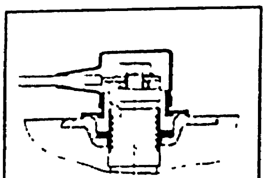




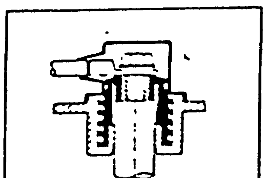
TATA BP SOLAR

Annexure A1





Pole lead-through assembly
Single cells



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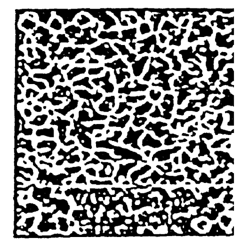
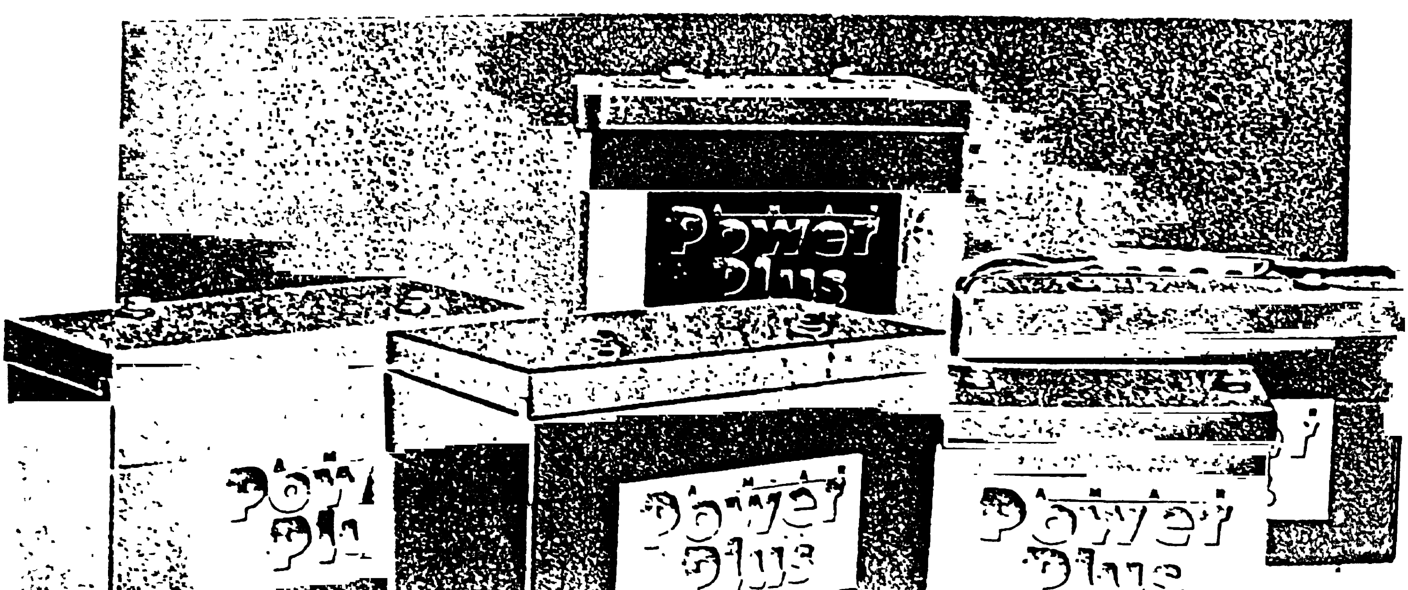
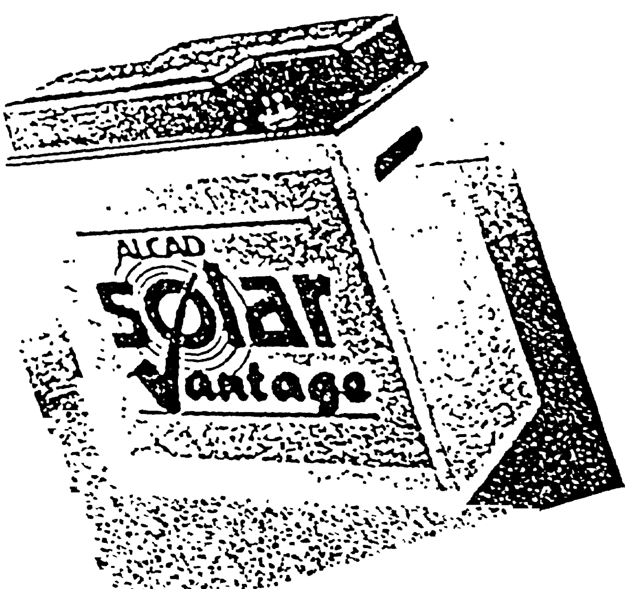
Block batteries

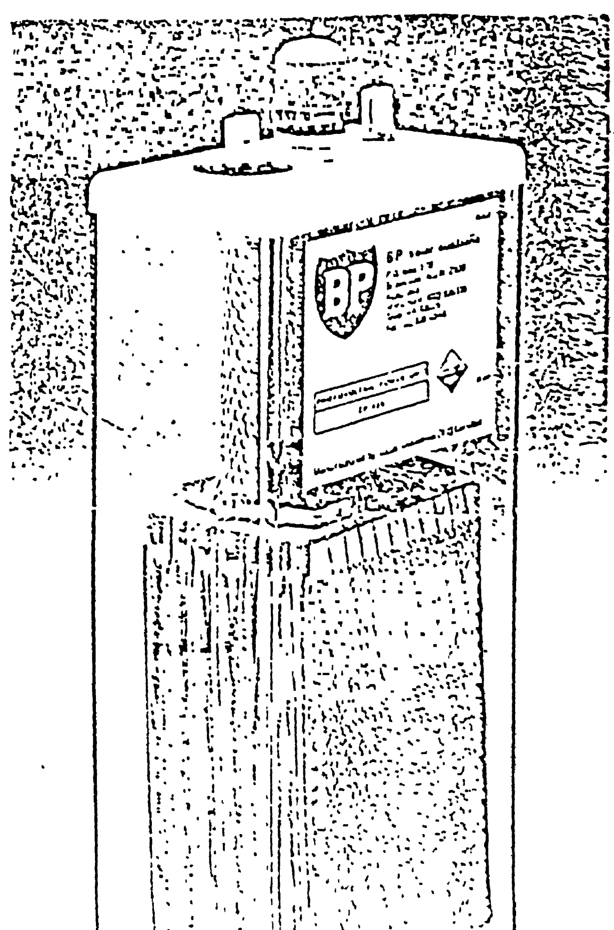




Annexure A2


SUNICA
NIFE
Nickel Cadmium Battery
Type
SUN 14-5


ALCAD
solar
Vantage


BP

Annexure A3

EXIDE SOLAR BATTERIES

Type	Capacity in Ah at 27°C when discharged at		Overall Dimensions (mm)				Cell Weight (kg) ± 5%		Electrolyte			Initial Charging			
									Approx Volume (Litre)	Sp. gr. at 27°C		Input (Ah)		Current (Amps)	
	10 hr Rate to 1.9 V per cell	120 hr Rate to 1.9 V per cell	Length ± 3 mm	Width ± 3 mm	Container Height ± 3 mm	Total Height ± 5 mm	Dry	Filled with Acid		Filling in	Service	First Portion	Second Portion	Starting rate	Finishing Rate
Single Cell (2 V nominal)															
2TSV45P	31	45	94	159	318	392	3.1	7.2	3.3	1.220	1.240	96	48	4.00	2.00
2TSM65P	44	65	113	159	398	473	3.9	10.0	5.0	1.220	1.240	132	66	5.50	2.75
2TSV90P	62	90	94	159	318	392	4.5	8.3	3.1	1.220	1.240	186	93	7.75	3.90
2TSV115P	80	115	94	159	318	392	5.5	9.2	3.0	1.220	1.240	240	120	10.00	5.00
2TSM125P	86	125	113	159	398	473	5.8	11.5	4.7	1.220	1.240	258	129	10.75	5.40
3 cell Monobloc (6 volt nominal)															
6TSV45H	31	45	315	181	370	400	16.5	28.5	9.6	1.220	1.240	96	48	4.00	2.00
6TSV90H	62	90	315	181	370	400	20.6	32.0	9.0	1.220	1.240	186	93	7.75	3.90
6TSV115H	80	115	315	181	370	400	23.5	34.5	8.7	1.220	1.240	240	120	10.00	5.00

Recharging current to be not less than 0.1 I_{10} and not more than finishing rate after 2.25 Volts per cell.

TATA BP SOLAR BATTERY RANGE

Sl No	Battery Type	Voltage V	Container Material	Capacity AH						Dimension			Weight
				5hr	10hr	25hr	50hr	100hr	120hr	L	W	H	Wet
1.	Solar 6 - 60	6	Hard Rubber	35	40	43	48	56	60	348	172	345	28.0
2.	Solar 6 - 90	6	Hard Rubber	52	60	65	72	84	90	348	172	345	31.0
3.	Solar 6 - 120	6	Hard Rubber	70	80	86	96	112	120	314	172	345	33.5
4	Solar 6 - 180	6	Hard Rubber	104	120	130	144	168	180	440	176	385	49.0
5.	Solar 6 - 240	6	Hard Rubber	139	160	173	192	224	240	440	176	385	51.0
6.	Solar 2 - 450	2	Hard Rubber	261	300	323	361	420	450	238	181	460	36.0
7.	Solar 2 - 600	2	Hard Rubber	348	400	430	482	560	600	378	188	503	57.0
8.	Solar 2 - 750	2	Hard Rubber	435	500	538	602	700	750	378	188	503	60.0
9.	Solar 2 - 900	2	Hard Rubber	522	600	645	723	840	900	376	192	595	70.5
10	Solar 2 -1500	2	Hard Rubber	870	1000	1075	1205	1400	1500	415	230	740	128.0
11.	Solar 6 - 363	6	Poly Propylene	209	240	258	289	336	363	490	170	510	63.3
12	Solar 2 - 566	2	Poly Propylene	326	375	403	452	525	566	378	188	503	57.0
13	Solar 2 - 987	2	Hard Rubber	566	650	699	783	910	987	376	192	595	74.0

Annexure B1

THE STANDARD BATTERIES LTD. BOMBAY-400 088.
PRODUCT DESIGN DEPARTMENT.

TECHNICAL DATA ON SOLAR CELLS

SL. No.	BATTERY TYPE. (B.P SOLAR.	CAPACITY @ 10 Hrs. AH.	BTY. VOLTAGE V	SBL BATTERY TYPE.	CAPACITY @ 10-Hrs. 1.75V AH.	CAPACITY @ 10-Hrs. 1.85V AH.	DIMENIONS L ±5 mm	W ±5 mm	H max mm	WEIGHT (APPRX) DRY Kg.	FILLED Kg.	ELECTROLYTE VOLUMS/UNIT Sp. Gr. 1.23 Ltrs.
01	12 P 58	35	12	6SPg 1B/LM	35	33	450	175	385	29.0	41.5	10.0
02	12 P 108	65	12	8SPg 2B/LM	65	62	450	175	385	38.0	47.5	9.5
03	12 P 157	94	12	6SPg 3B/LM	95	85	450	175	385	44.0	55.0	9.8
04	6 P 207	124	6	3SPg 4B/LM	120	115	383	187	380	34.5	50.0	12.6
05	6 P 363	218	6	3SPg 6B/LM	200	190	450	175	385	42.0	53.5	11.5
06	2 P 425	255	2	SPg-6D/LM	250	238	187	185	535	22.0	30.0	7.0
07	2 P 566	340	2	SPg-8D/LM	350	335	276	188	500	33.5	47.0	11.0
08	2 P 641	385	2	SPg-10D/LM	400	380	276	186	500	37.5	50.5	10.5
09	2 P 779	467	2	SPg-12D/LM	500	475	378	194	550	45.0	62.5	14.0
10	2 P 886	532	2	SPg-14D/LM	550	522	378	194	550	49.0	65.5	13.5
11	2 P 987	592	2	SPg-12E/LM	600	570	346	198	600	55.0	77.0	14.5
12	2 P 1101	661	2	SPg-11G/LM	660	627	346	198	660	63.0	81.0	16.5

NOTE:- 1. INITIAL FILLING SP.GR. 1.230 ± 0.005

2. TESTING SP.GR. 1.245 ± 0.005

3. ALL CAPACITIES MEASURED AT 27°C & TO AN END VOLTAGE 1.85V OR 1.75V PER CELL SPECIFICATION TO ± 10%.

4. LONGER CAPACITIES ARE OBTAINABLE BY CONNECTING LIKE CELLS IN PARALLEL. HIGHER VOLTAGES ARE AVAILABLE FROM CONNECTING LIKE CELLS IN SERIES.

UB-MEC
BATTERIES LTD

6

SL. NO.	TYPE	CAPACITY AT 10 Hr. RATE AT 27°C	DISCHARGE CURRENT AT 10Hr. RATE TO AN END-VOLTAGE OF 1.85V PER CELL IN AMPS	CHARGING CURRENT IN AMPS: INITIAL CHARGE	NORMAL CHARGE: UPTO 2.4V PER CELL	TILL END
1	3ME70HLM	6V, 70 Ah.	7	3.5	10.5	5.0
2	3MQ120HLM	6V, 120Ah.	12	6.0	18	9.0
3	3MQ160HLM	6V, 160Ah.	16	8.0	24	12
4	3ME75HLM	6V, 75Ah	7.5	3.5	11	5.5
5	3MA100HLM	6V. 100 Ah.	10	5.0	15	7.5
6	3MA130HLM	6V, 130Ah	13	6.5	19.5	10

CHARGING INSTRUCTIONS:-

INITIAL CHARGING DURATION : 80 Hrs.

NORMAL CHARGING DURATION : 10 Hrs MINIMUM

MAXIMUM TEMPARATURE DURING CHARGING : [illegible]

FILLING SP.GR. OF ELECTROLYTE: 1.200 ±0.00[illegible]

[illegible] GR. OF ELECTROLYTE : 1.2[illegible]5 [illegible]

Annexure B2

BP SOLAR RANGE

All battery capacities are measured at 25°C, to an end of discharge voltage of 1 8 volts per cell Specification to ± 10%.

Battery Type	Battery Voltage (v)	CAPACITY (AH)		DIMENSIONS (mm)			WEIGHT (Kg)	
		10 hr	100 hr	Length	Width	Height	Wet	Dry
6P207	6	95	207	272	205	379	37 5	23
2P425	2	196	425	124	206	546	23 5	14 5
2P566	2	261	566	166	206	546	31.5	19
2P779	2	358	779	191	210	721	46 5	26
2P886	2	408	886	191	210	721	49	29
2P1101	2	506	1101	233	210	721	60 5	35 5

AMAR POWER PLUS RANGE

Battery Specifications

Model	Voltage	Nominal AH Cap.	Overall Dimensions L mm	W mm	H mm	Weight Kg	Amperes to 1.75 VPC at 25°C 15min	30min.	1hr	2hr	3hr	4hr	5hr	10hr
1235	12	35	200	169	167	14	55 0	36 0	19 0	11 5	8 7	7 0	6 0	3 5
1255	12	55	265	173	216	19	78 0	50 3	31 2	19 1	14 1	11 5	9 5	5 5
1275	12	75	305	173	216	29	134 8	88 4	47 3	28 1	21 2	17 2	14 3	7 5
6165	6	165	305	173	216	28	263 0	170 0	98 0	59 0	44 0	35 5	29 8	15 5
4250	4	250	305	173	216	29	394 3	248 6	149 0	89 5	67 0	54 5	45 5	[illegible]

AMAR Power Plus Series are also available in factory pre-wired and assembled cabinet systems or rack arrangements

Annexure B3

SUNICA BATTERY RANGE

TYPE	VOLTAGE	CAPACITY Ah		DIMENSIONS mm *			TOTAL * WEIGHT kg	ELECTROLYTE * RESERVE ** dm³
	V	5 h	100 h	L	W	H		
SUN 3-5	6	34	37	137	195	349	13	0.3
SUN 7-5	6	68	73	192	195	349	21	0.4
SUN 10-5	6	102	110	252	195	349	28	0.5
SUN 14-5	6	139	150	312	195	349	37.5	0 8
SUN 17-5	6	173	187	377	195	349	45	0 9
SUN 21-5	6	208	225	437	195	349	51	1.1
SUN 24-3	3 6	244	263	336	195	349	38 5	1 3
-2	2.4	244	263	228	195	349	25 5	1.3
SUN 28-3	3.6	278	300	372	195	349	43	1.5
-2	2.4	278	300	252	195	349	29	1.5
SUN 31-3	3 6	313	338	411	195	349	49 5	1.7
-2	2 4	313	338	278	195	349	33	1 7
SUN 35-3	3 6	348	376	450	195	349	51	1.8
-2	2 4	348	376	304	195	349	34	1 8
SUN 38-1	1 2	382	413	171	195	349	19	2.0
SUN 42-1	1 2	417	450	183	195	349	20	2.1
SUN 52-1	1 2	522	564	232	195	349	27	2.7
SUN 63-1	1 2	626	676	268	195	349	31	3 2
SUN 70-1	1 2	696	751	304	195	349	36	3.6
SUN 84-1	1.2	835	902	352	195	349	41	4 2
SUN 87-1	1 2	870	940	377	195	349	45	4.5
SUN 104-1	1 2	1040	1123	437	195	349	51	5.3

* APPROXIMATE VALUES
** /CELL

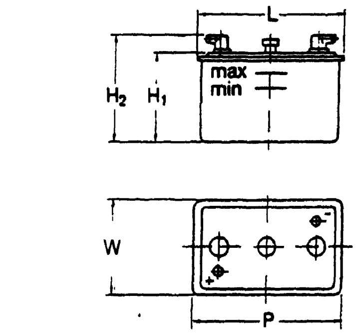
NOACK BATTERY RANGE

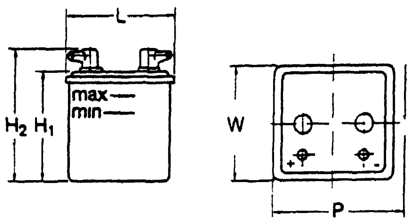
Cell type	Capacity Ah/10 h to 1.83 V/cell	Dimensions mm			Weight per cell kgs		Number of terminals
		Length	Width	Height x)	Excl acid	Incl acid	
2 SR 21 ELSG	100	109	212	426	9	14	2
3 SR 21 ELSG	150	109	212	426	11	16	2
4 SR 21 ELSG	200	109	212	426	13	18	2
5 SR 21 ELSG	250	130	212	426	16	22	2
6 SR 21 ELSG	300	151	212	426	18	25	2
5 SR 30 ELSG	380	130	212	542	21	29	2
6 SR 30 ELSG	456	151	212	542	24	34	2
7 SR 30 ELSG	532	172	212	542	28	39	2
6 SR 44 ELSG	660	151	212	717	33	47	2
7 SR 44 ELSG	770	216	197	717	42	61	4
8 SR 44 ELSG	880	216	197	717	46	64	4
9 SR 44 ELSG	990	216	239	717	52	75	4
10 SR 44 ELSG	1100	216	239	717	56	78	4
11 SR 44 ELSG	1210	216	281	717	62	88	4
12 SR 44 ELSG	1320	216	281	717	65	92	4
13 SR 44 ELSG	1430	220	370	693	70	106	6
14 SR 44 ELSG	1540	220	370	693	74	110	6
15 SR 44 ELSG	1650	220	370	693	77	114	6
16 SR 44 ELSG	1760	220	450	693	81	129	6
17 SR 44 ELSG	1870	220	450	693	89	133	6
18 SR 44 ELSG	1980	220	450	693	93	137	6
19 SR 44 ELSG	2090	220	450	693	97	140	6
20 SR 44 ELSG	2200	220	450	693	101	144	6

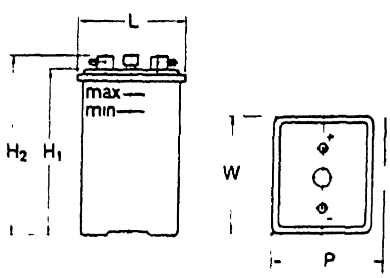
x) Including flame arresting vent plug

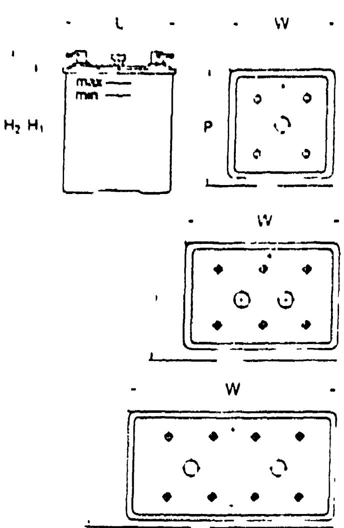
Annexure B4

VARTA bloc Type Range







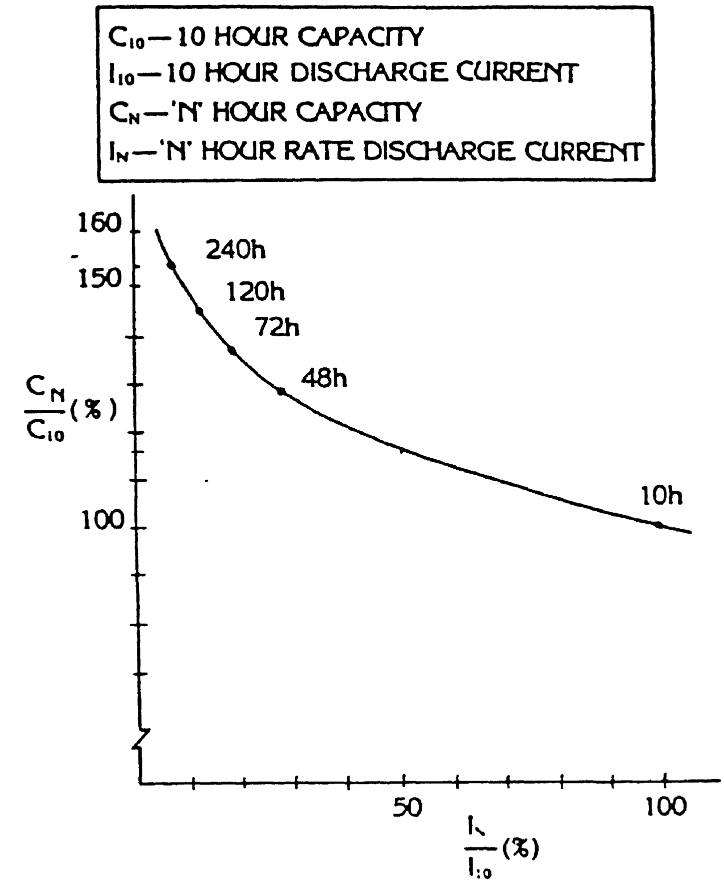


Type	10 h Cap. Ah	L	W	H_2	H_1	P*)	Weight kg**)	Acid kg***)	Type No ****)
Vb 611	12,5	125	176	275	242	128	9,84	2,01	16013103
Vb 612	25	125	176	275	242	128	11,45	2,24	16013203
Vb 613	37,5	203	176	275	242	206	17,16	3,91	16013303
Vb 614	50	203	176	275	242	206	18,78	4,13	16013403
Vb 615	62,5	281	176	275	242	284	24,04	5,81	16013503
Vb 616	75	281	176	275	242	284	25,65	6,03	16013603
Vb 624	100	283	229	332	300	286	36,61	11,02	16025403
Vb 625	125	283	229	332	300	286	39,72	10,43	16025503
Vb 626	150	283	229	332	300	286	42,69	10,81	16025603
Vb 427	175	247	229	332	300	250	34,65	9,21	16025703
Vb 428	200	247	229	332	330	250	36,64	9,47	16025803
Vb 2305	250	131	275	440	390	134	29,1	8,62	190520517
Vb 2306	300	131	275	440	390	134	31,2	8,62	190520617
Vb 2307	350	197	275	440	390	200	42,0	14,20	190520717
Vb 2308	400	197	275	440	390	200	44,2	14,20	190520817
Vb 2309	450	197	275	440	390	200	46,4	14,20	190520917
Vb 2310	500	242	275	440	390	245	54,5	17,80	190521017
Vb 2311	550	242	275	440	390	245	56,7	17,80	190521117
Vb 2312	600	242	275	440	390	245	58,8	17,80	190521217
Vb 2407	700	383	222	550	500	393	89,5	28,9	1910207175
Vb 2408	800	383	222	550	500	393	94,7	28,3	1910208175
Vb 2409	900	383	222	550	500	393	99,7	28,4	1910209175
Vb 2410	1000	383	222	550	500	393	104,9	27,7	1910210175
Vb 2411	1100	383	307	550	500	393	131,5	41,9	1910211175
Vb 2412	1200	383	307	550	500	393	136,8	41,0	1910212175
Vb 2413	1300	383	307	550	500	393	141,7	40,4	1910213175
Vb 2414	1400	383	307	550	500	393	147,0	40,5	1910214175
Vb 2415	1500	383	307	550	500	393	152,1	39,8	1910215175
Vb 2416	1600	383	392	550	500	393	178,8	54,0	1910216175
Vb 2417	1700	383	392	550	500	393	184,0	53,2	1910217175
Vb 2418	1800	383	392	550	500	393	189,1	52,5	1910218175
Vb 2419	1900	383	392	550	500	393	194,2	52,6	1910219175
Vb 2420	2000	383	392	550	500	393	199,4	51,9	1910220175

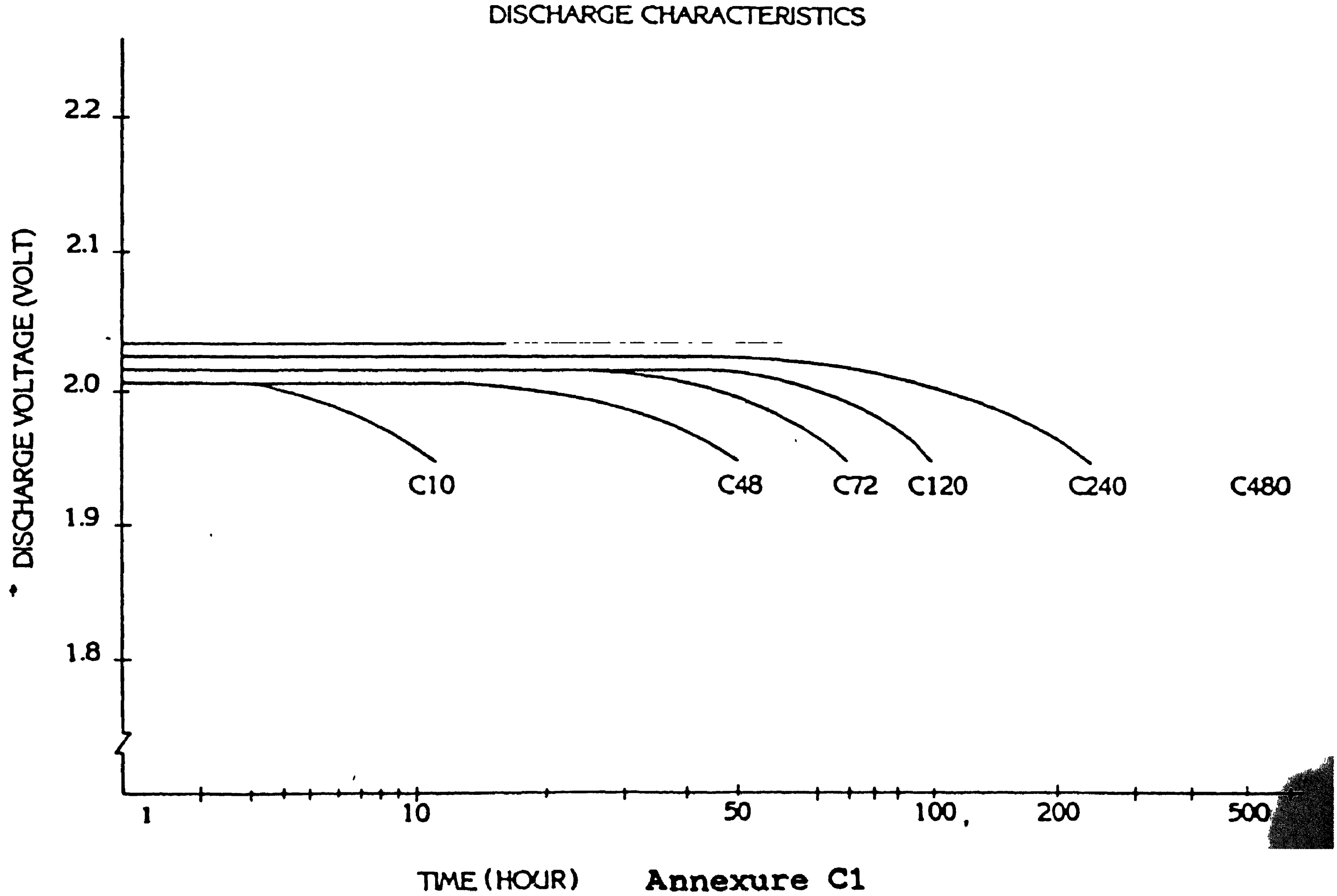
*) Installation length
**) Total weight inclusive acid
***) Acid density 1,24 kg/l
****) Type number for dry charged cells

EXIDE SOLAR BATTERY

PERCENT INCREASE IN CAPACITY
RELATIVE TO 10 HOUR CAPACITY

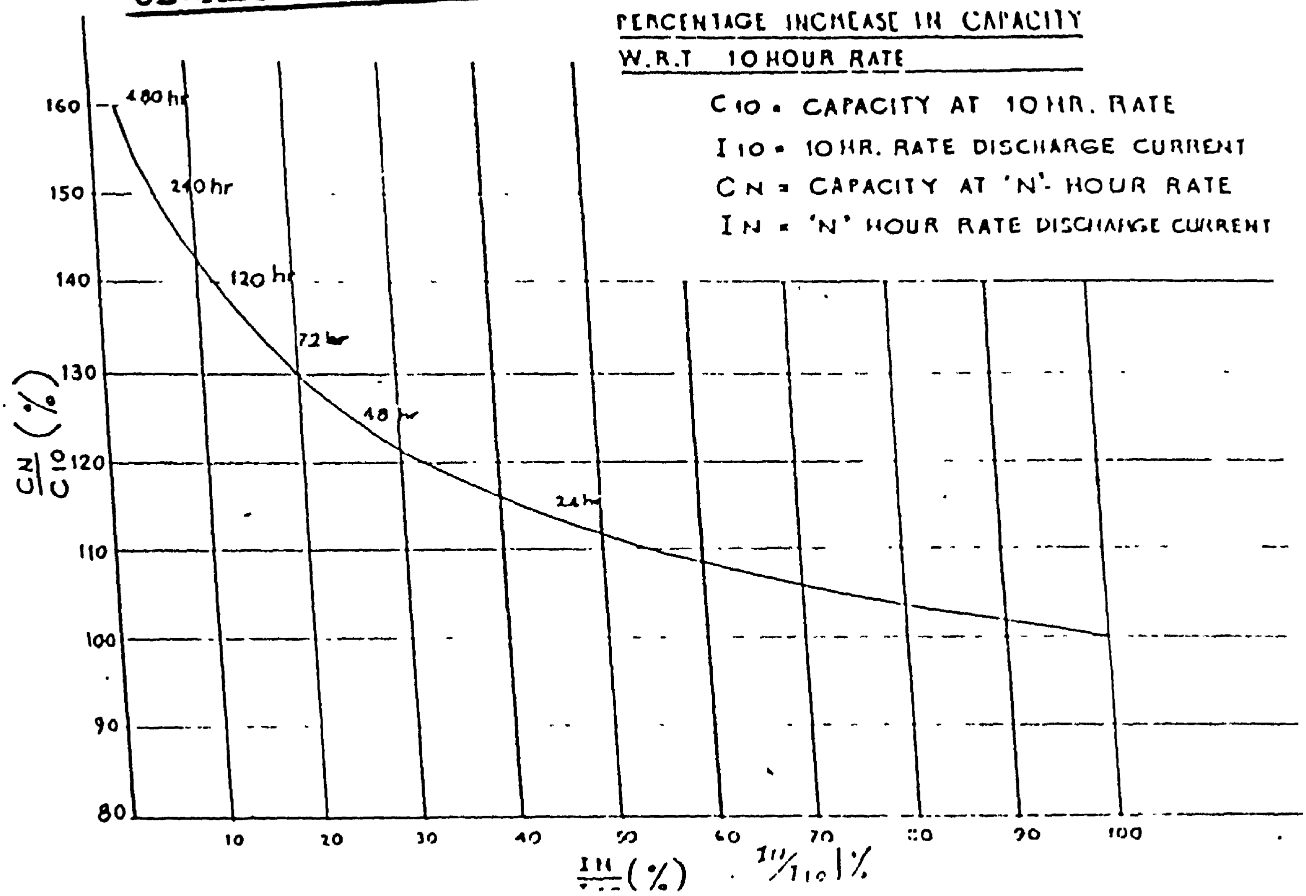


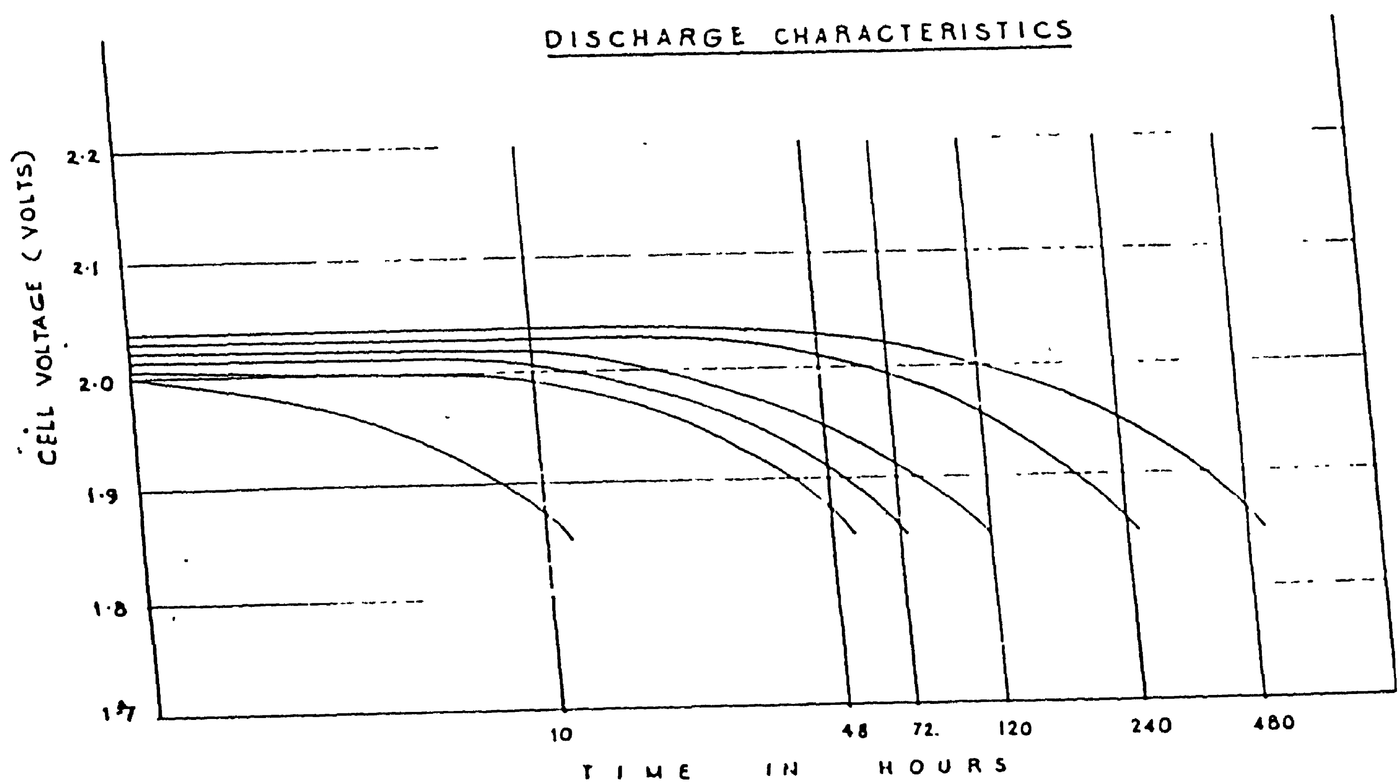
DISCHARGE CHARACTERISTICS



Annexure C1

UB-MEC SOLAR PV BATTERY

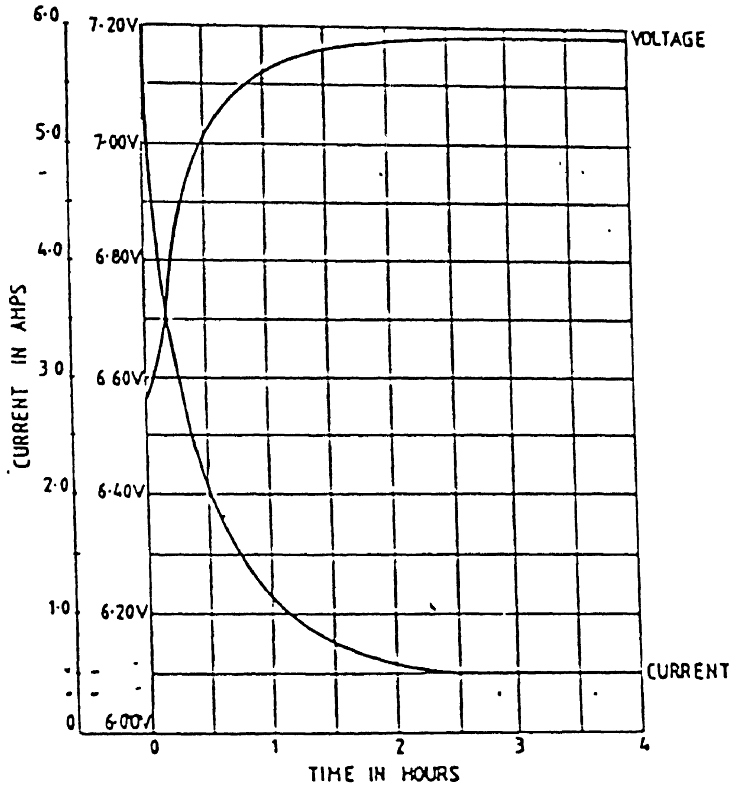




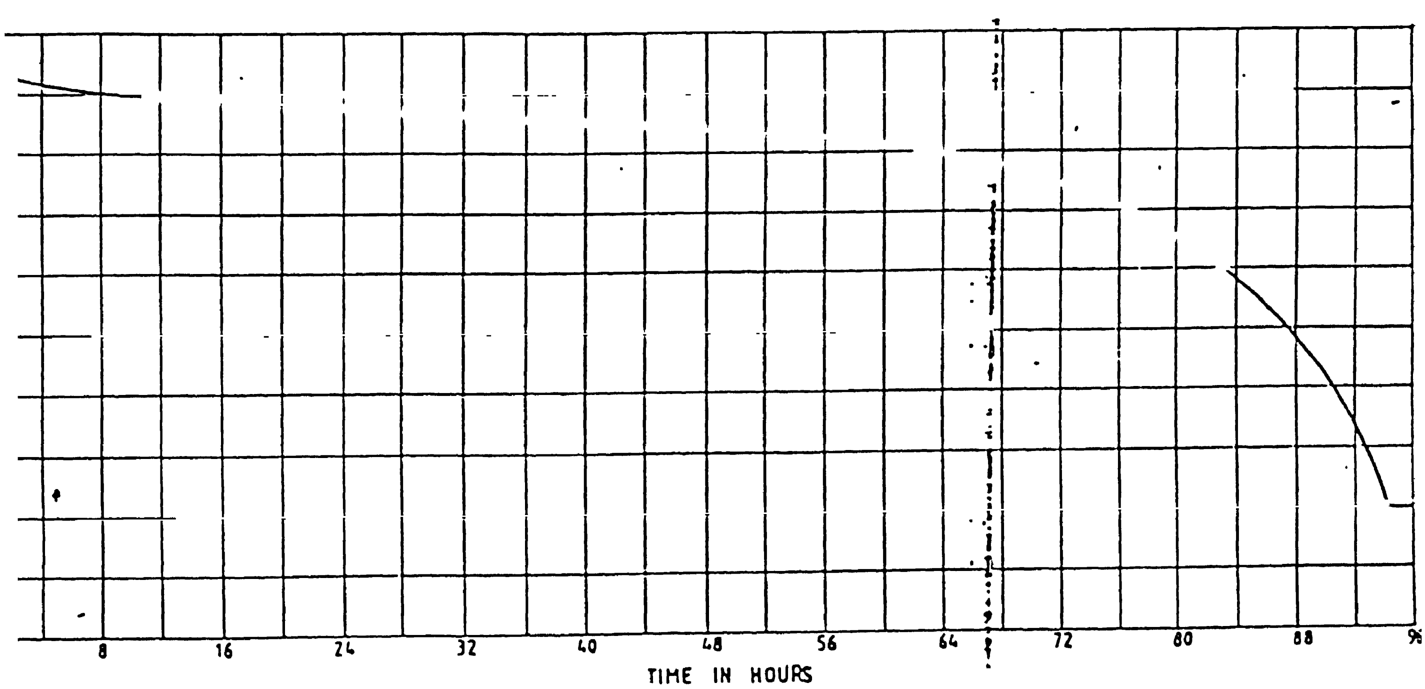
Annexure C2

TATA BP SOLAR BATTERY

SOLAR 6 - 60 CONSTANT VOLTAGE CHARGE CURVE AT 2·40V/CELL FROM 5% U.O.D. WITH CURRENT LIMITATION OF 0·1C_A AT 40°C.

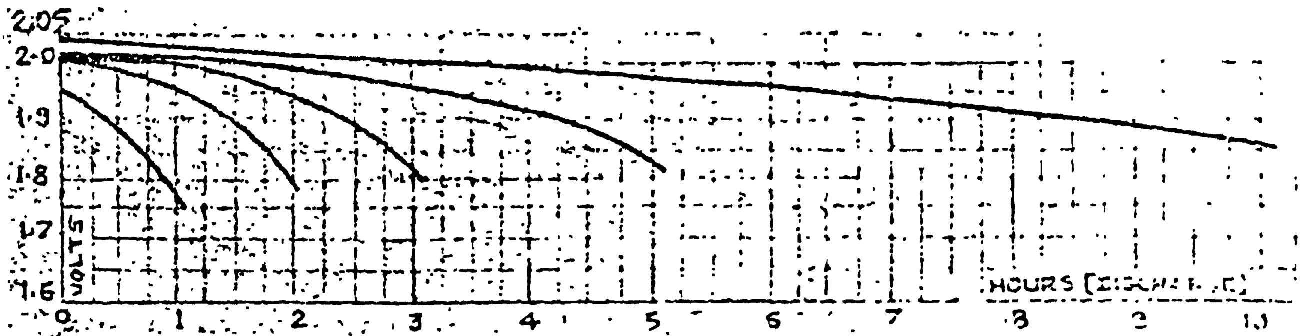


SOLAR 6-60 C_{100} DISCHARGE CURVE AT 0°C. DISCHARGE CURRENT - 0·84 AMPS.



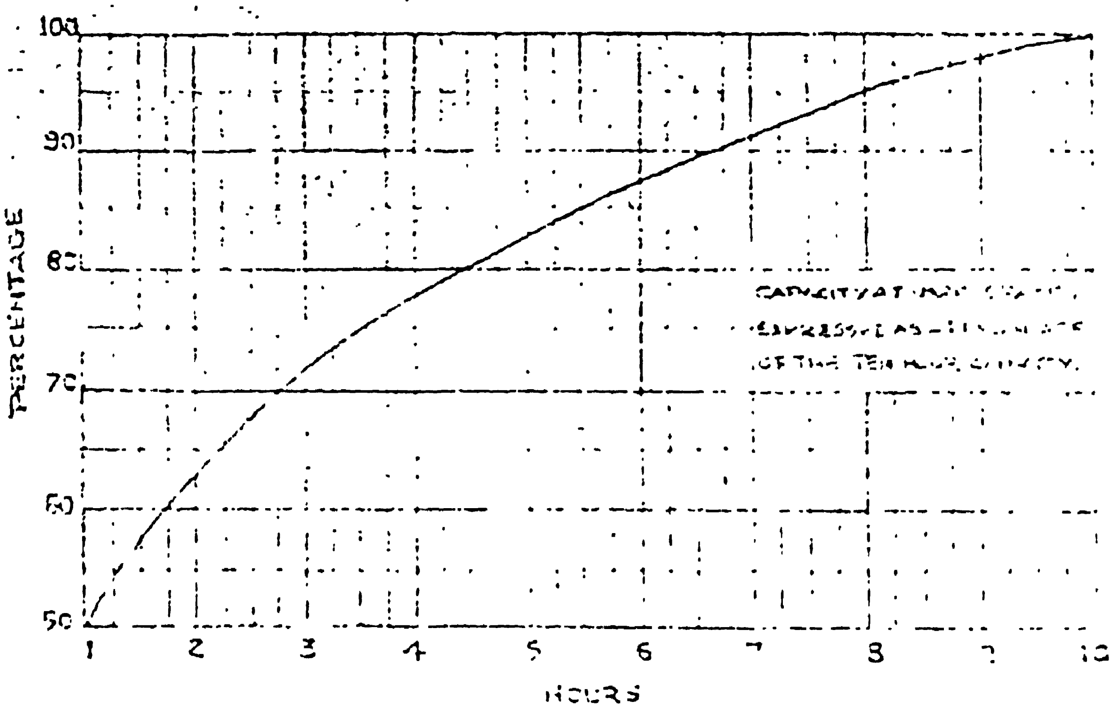
Annexure C3

STANDARD SOLAR BATTERY



The diagram show curves of voltage for discharges in 1,2,3,5 [illegible]

CAPACITIES AT VARIOUS RATES OF DISCHARGE



CAPACITY IN AMPERE HOURS

[EXPRESSED [illegible] THE AMPERE HOURS [illegible]

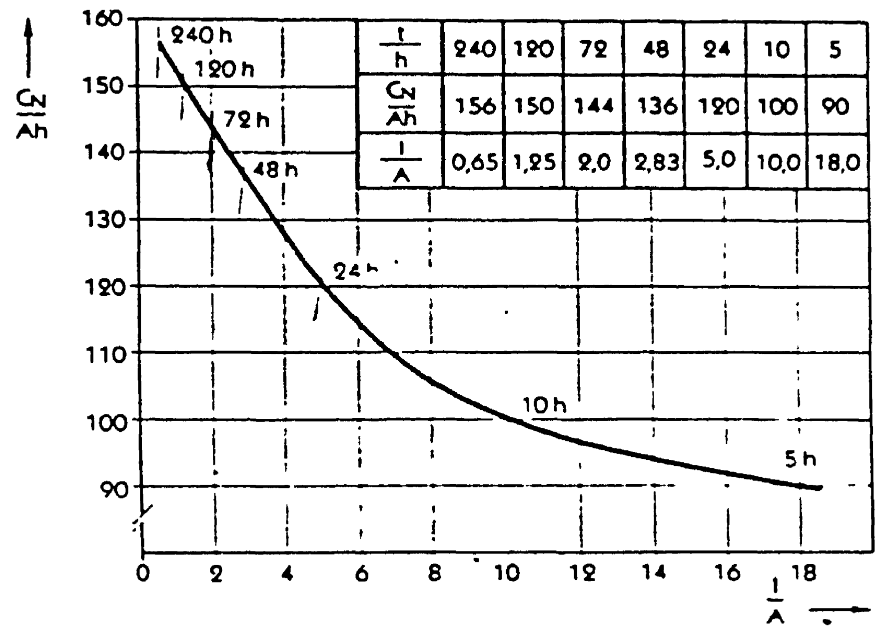
WHEN DISCHARGING IN

	1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 hours	8 hours	9 hours	10 hours
	5[illegible]	63.3%	71.7%	78.2%	83.3/	[illegible]	[illegible]	95%	97.9%	[illegible]
FINAL VOLTAGE	1.75	1.74	1.76	1.81	1.82	1.83	1.83	1.84	1.84	[illegible]

VARTA BLOC SOLAR BATTERY

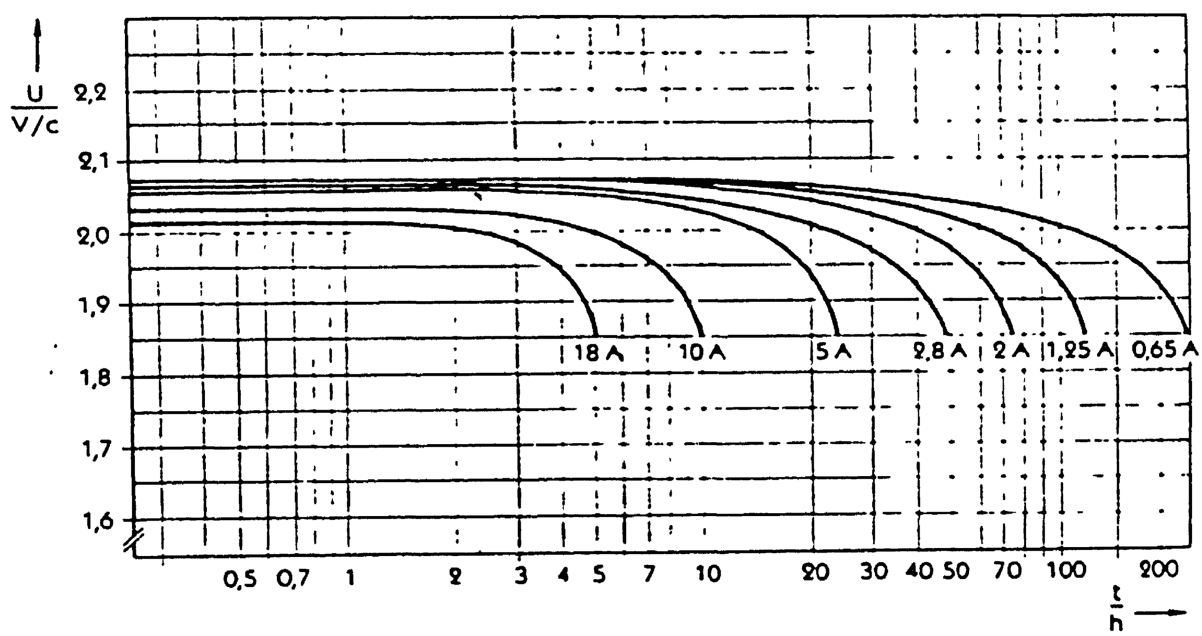
Characteristic data

Capacity Curve of VARTA bloc Cells related to a rated capacity of 100 Ah.



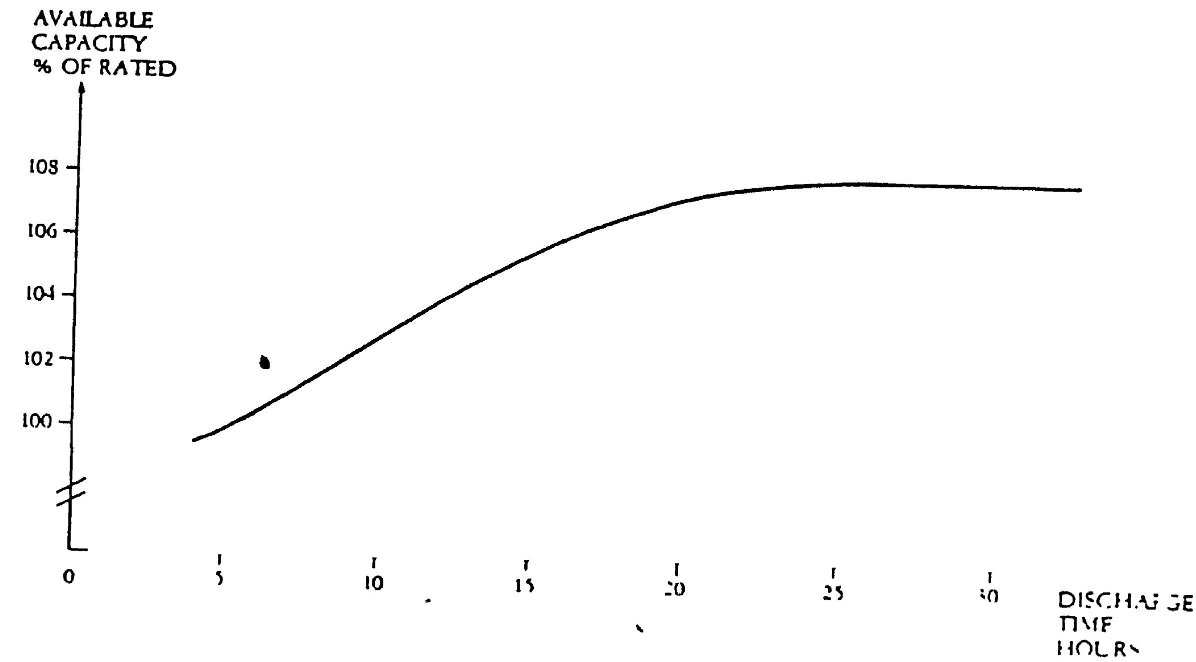
t/h	240	120	72	48	24	10	5
CN/Ah	156	150	144	136	120	100	90
I/A	0,65	1,25	2,0	2,83	5,0	10,0	18,0

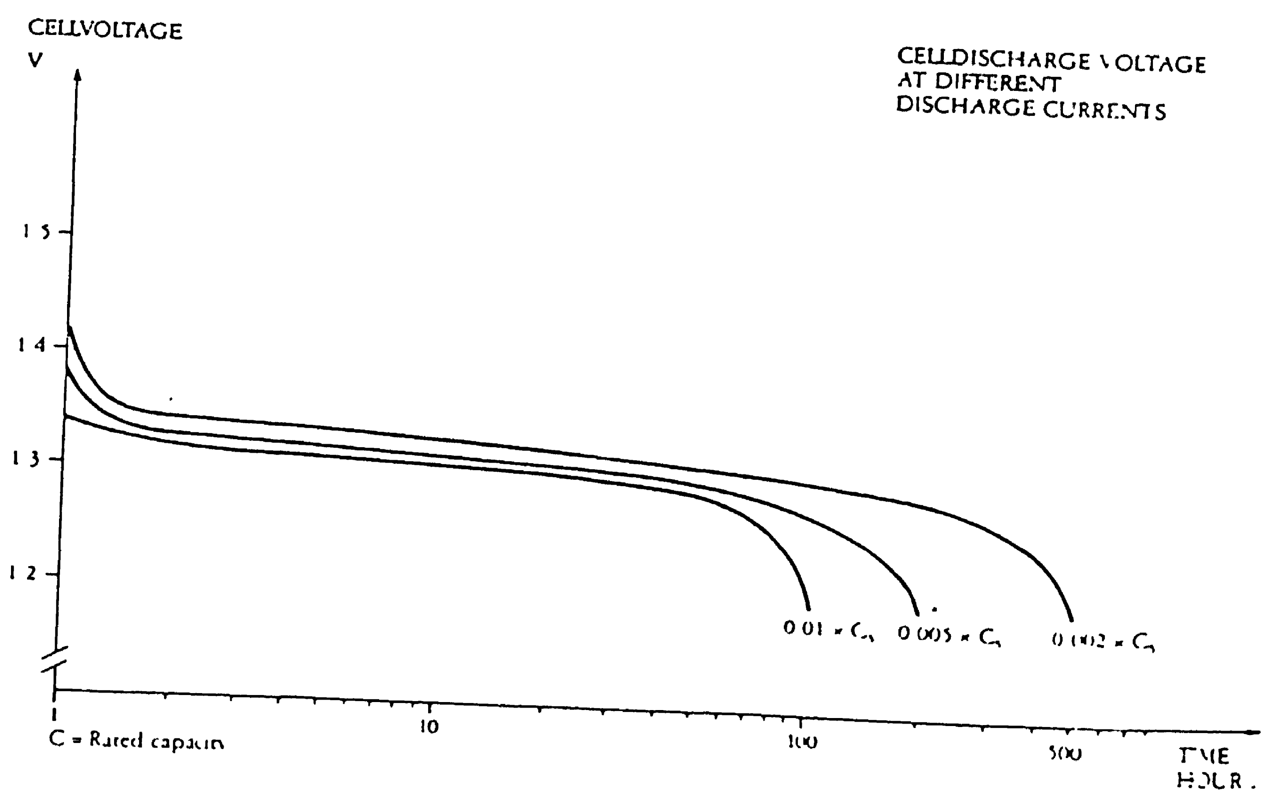
Discharge voltages for VARTA bloc Cells in dependance upon the discharge current related to a rated capacity of 100 Ah



Annexure C5

SUNICA NiCd BATTERY





Annexure C6

Annexure D

Addresses

Chloride India Limited
Exide House
59 E Chowringhee Road
Calcutta - 700 020

The Standard Batteries Limited
Vakola, Santa Cruz
Bombay - 400 055.

UB-MEC Batteries Limited
MEC Factory Road
Yeswantpur
Bangalore - 560 022.

TATA BP Solar India Private Limited
A 101 Block II
KSSIDC Multistorey Blocks
Electronic City, Hebbagodi
Hosur Road
Bangalore 562 158.

AMARA Raja Batteries Limited
Renigunta - Cuddapah Road
Karakambadi - 517 520
Tirupati (A.P.).

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